

# Minimal Functional Habitat

## Final Review Presentation



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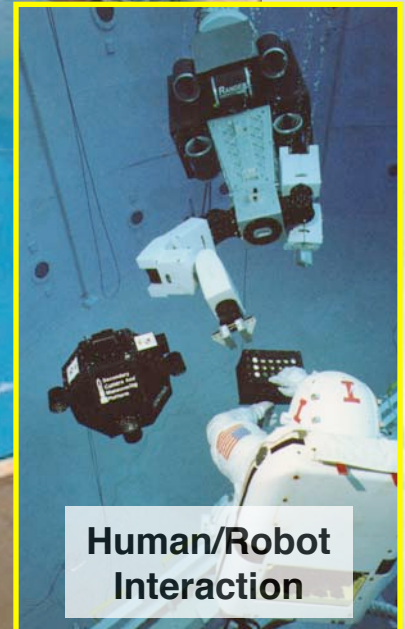
# Agenda

- Introduction
- Synopsis of data collection
  - Literature review
  - Survey and analysis
- Design methodology
  - Three separate preliminary designs
  - Synthesis of target concept
- Systems trade studies
- Mockup fabrication and testing
- Final design and growth options





# Overview of the UMd Space Systems Lab



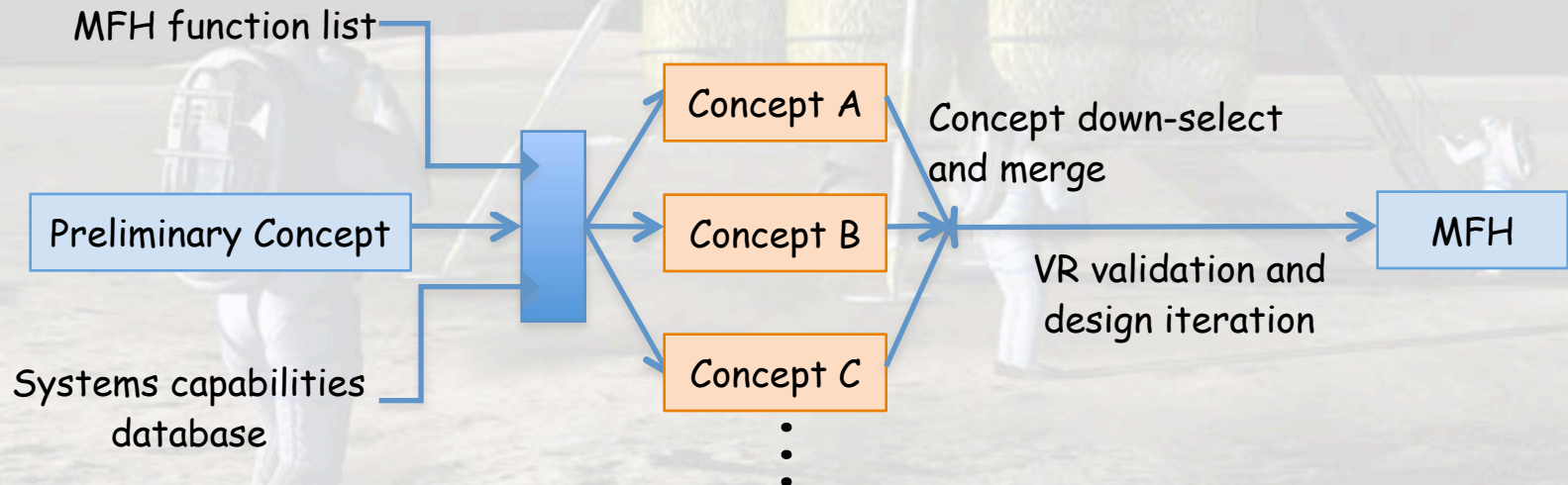
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# Concept Design Process

- UMd investigators develop multiple independent design concepts
  - Preliminary concepts provide a starting point
  - Concepts will explore full range of the design space
  - Synthesize from function lists and systems capabilities database to determine which functions to provide, and which systems to use
  - Concepts will meet MFH functionality, while minimizing costing function for systems





# Defining Habitability

- T.M. Fraser (1968) defines habitability as the:  
“...*equilibrium state resulting from the interactions among the components of a man-machine-environment-mission complex which permit man to maintain physiological homeostasis, adequate performance, and acceptable social relationships.*” Source: *Habitability Issues in Long-Duration Undersea and Space Missions* Jul 1972

## Three levels of habitability, as defined by Preiser:

1. **Health and safety**
2. **Function and efficiency**
3. **Psychological wellbeing**

## Nine habitability elements, as defined by Every and Parker:

1. **Environment**
2. **Architecture**
3. **Mobility**
4. **Food**
5. **Clothing**
6. **Personal Hygiene**
7. **Housekeeping**
8. **Communication**
9. **Off-duty activities**

- The purpose of this study is to sharpen this definition and expand on these elements by developing a methodology for ranking habitat functions in order to design an austere habitat that supports only the highest ranked functions



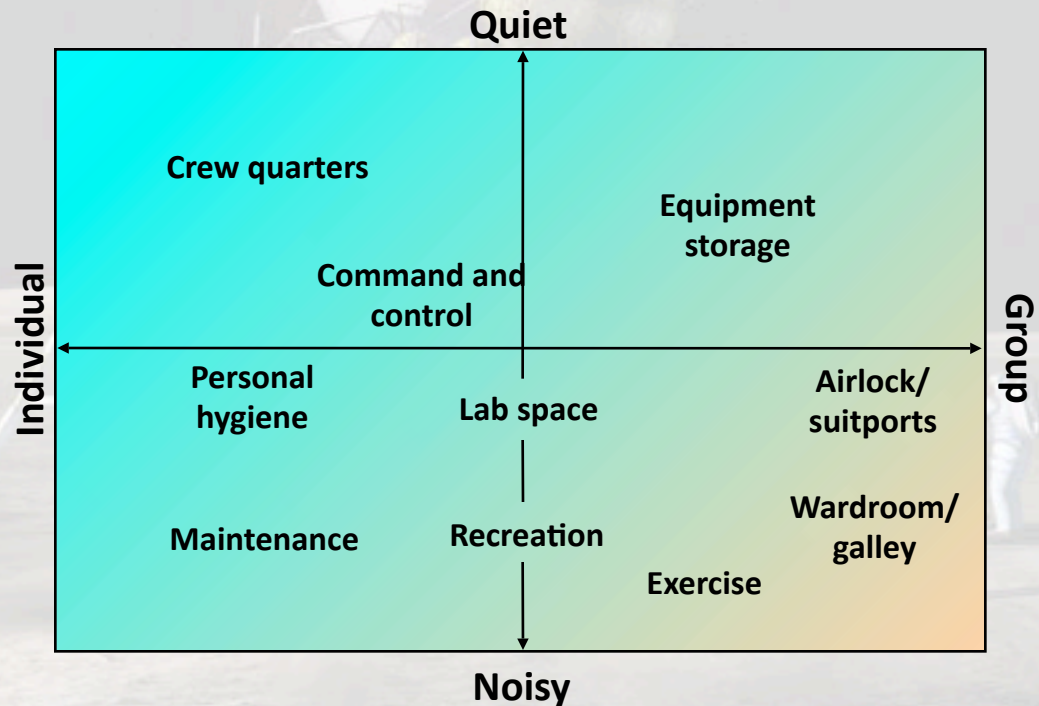
# Selected Comparable Past Designs

Name of Habitat	Overall Mass (kg)	Overall Volume (m <sup>3</sup> )	Crew	Mission Duration (days)
Lunar Surface Emergency Shelter	10,000	8.56	4	5
Concept 1	7,596	15.53	3	14
Pressured Lunar Rover	6,197	49.5	4	14
Pressured Lunar Rover	7,015	125.7	4	14
Scaled Apollo	14,965	25	4	21
Orion Zero Base Vehicle	17,535	40	4	21
MOLAB	3810	12.8	2	21
Concept 2	11,790	26.13	3	30
Concept 1	17,060	162.07	4	30
Concept 2	24,510	273.68	4	30
Concept 3	8,608	131.31	4	30
First Lunar Outpost	No Data	446.6	4	45
First Lunar Outpost	29,986	337.5	4	45



# Habitable Environment

- Requirements for life support, atmosphere, noise, lighting, and radiation derived from MSIS
- Functional areas should be zoned by noise level and by group or individual activities (Eckart)
- Approximately 10 m<sup>3</sup> per crew member for four crew on a 28-day mission (MSIS)
- Habitable volume selection largely a black art, multiple attempts to curve fit past spacecraft have been contradictory

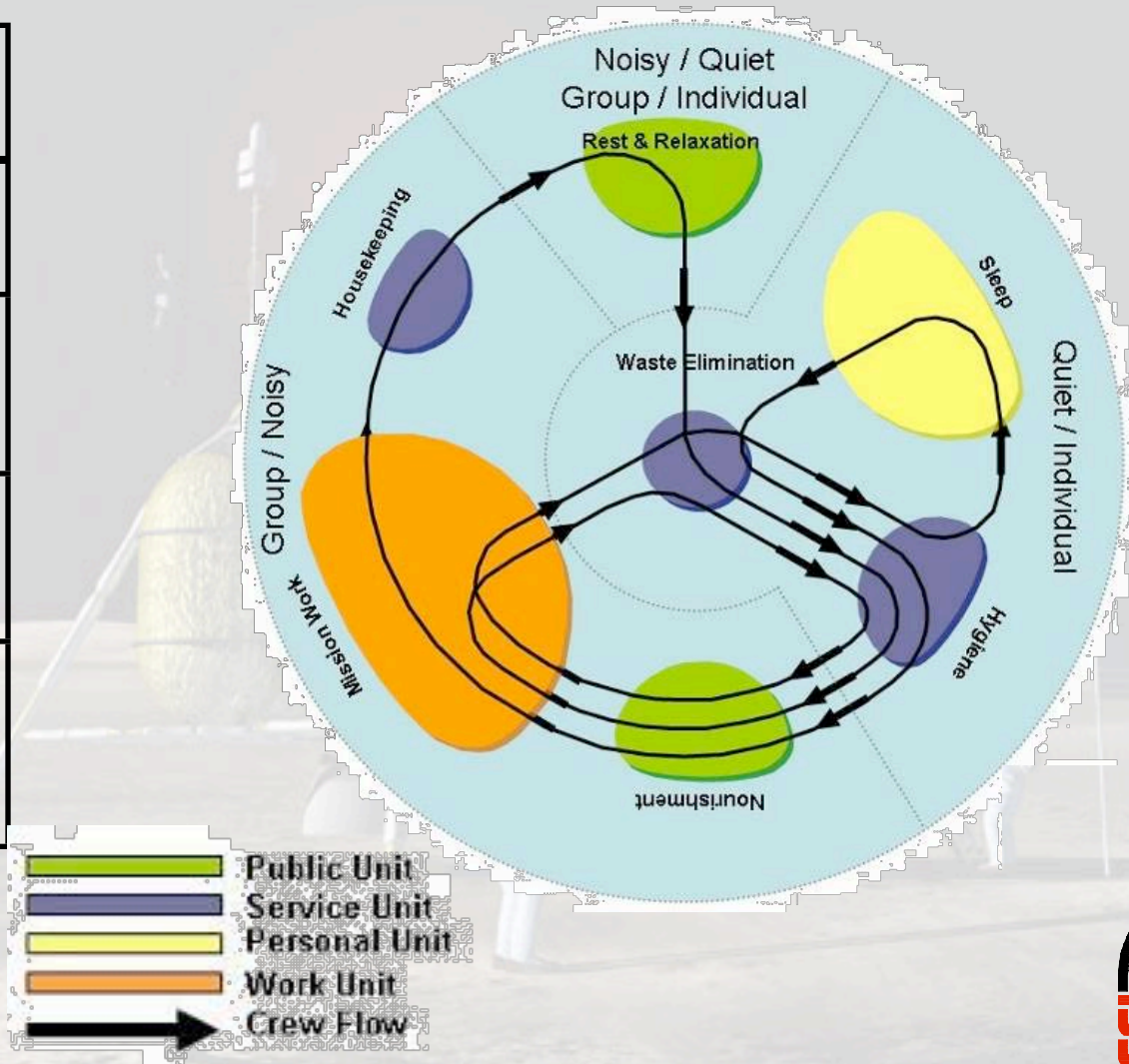




# Space Allocation and Crew Flow

Unit	Description	% of habitable volume
Work	Operational or Mission-related tasks	40%
Public	Dining, food, management, recreation, and exercise	25%
Personal	Sleeping, privacy, personal stowage	20%
Service	Hygiene, waste management, public stowage	15%

Data from Parker & Every (1972) and Schowalter & Malone (1972)





# Analytical Hierarchy Process

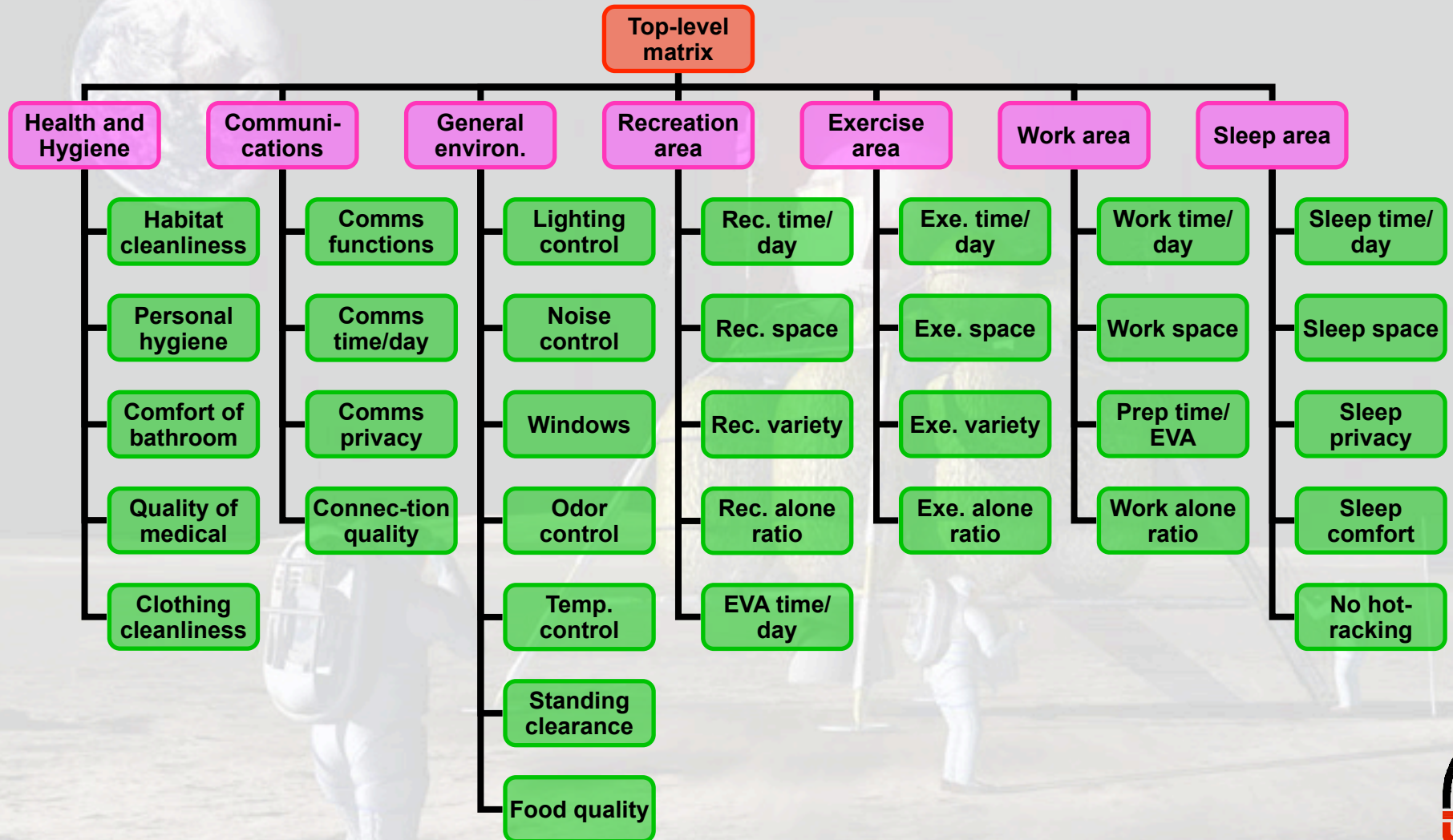
- Used an Analytical Hierarchy Process survey to determine the relative importance of possible habitat functions for an MFH
  - Life support assumed present
  - Two-level AHP ranks 34 functions based on 90 pair-wise rankings
- Targeted population with experience in remote/confined environments:
  - Astronauts
  - Submariners/ship crews
    - *“Submarines were found to be most similar overall to the space ship situation...”*
  - Artic/Antarctic research scientists
    - *“The south pole is the closest place to space on earth where a permanent, manned US presence exists, and represents a good scientific/logistics/operations analogue for future moon/mars missions”*

*Source: Habitability Issues in Long-Duration Undersea and Space Missions Jul 1972*

*Source: Antarctic Exploration: Proxy for Safe, Sustainable Exploration of the Moon and Mars*



# Survey Hierarchy



# Online AHP Survey

## Minimal Lunar Habitat Survey

### Introduction

This is a University of Maryland functioning lunar habitat. Your

### Scenario

You are to live in a confined, self-contained habitat for a brief period of time. The habitat must additionally provide for the following functions that the habitat could not otherwise provide.

### Instructions

You will be asked to rank the features into eight sections. For each pair of features, a number in parentheses represents the relative importance of the two features. Some sections will ask for your best estimate.



## Preliminary Questions



1. What type of confined environment do you prefer?

Antarctic Base

2. How much experience, in months, do you have living in a confined environment?

- ☐ < 1 month  
☐ 1 to 6 months  
☒ 7 to 12 months  
☐ > 12 months

3. What is your age?

22

4. What is your gender?

- ☒ Male  
☐ Female

5. What is your Nationality?

American



## Main Questions



### Top Level Features

1. How many hours per day would you ideally like to spend working (doing mission-related tasks) inside the habitat?

6

2. How many hours per day would you ideally like to spend working outside the habitat?

2

Keeping in mind that your basic life support needs will be met, evaluate the relative importance of quality in the following feature areas: [Hover Here For Instructions](#)

Feature 1	Ft. 1 is Much More Important	Ft. 1 is Moderately More Important	Ft. 1 is a Little More Important	Both Fts. are about as Important	Ft. 2 is a Little More Important	Ft. 2 is Moderately More Important	Ft. 2 is Much More Important	Feature 2
Quality of External Comms	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	Health & Hygiene
Quality of Habitat Environment	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Health & Hygiene
Quality of Habitat Environment	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Quality of External Comms
Amount of Work Time / Day	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	Health & Hygiene
Amount of Work Time / Day	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Quality of External Comms
Amount of Work Time / Day	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	Quality of Habitat Environment
Excursions from Habitat	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	Health & Hygiene
Excursions from Habitat	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Quality of External Comms
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Excursions from Habitat	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Amount of Work Time / Day
Amount of Work Time / Day	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Prep time per excursion

Next



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# Data Analysis Method

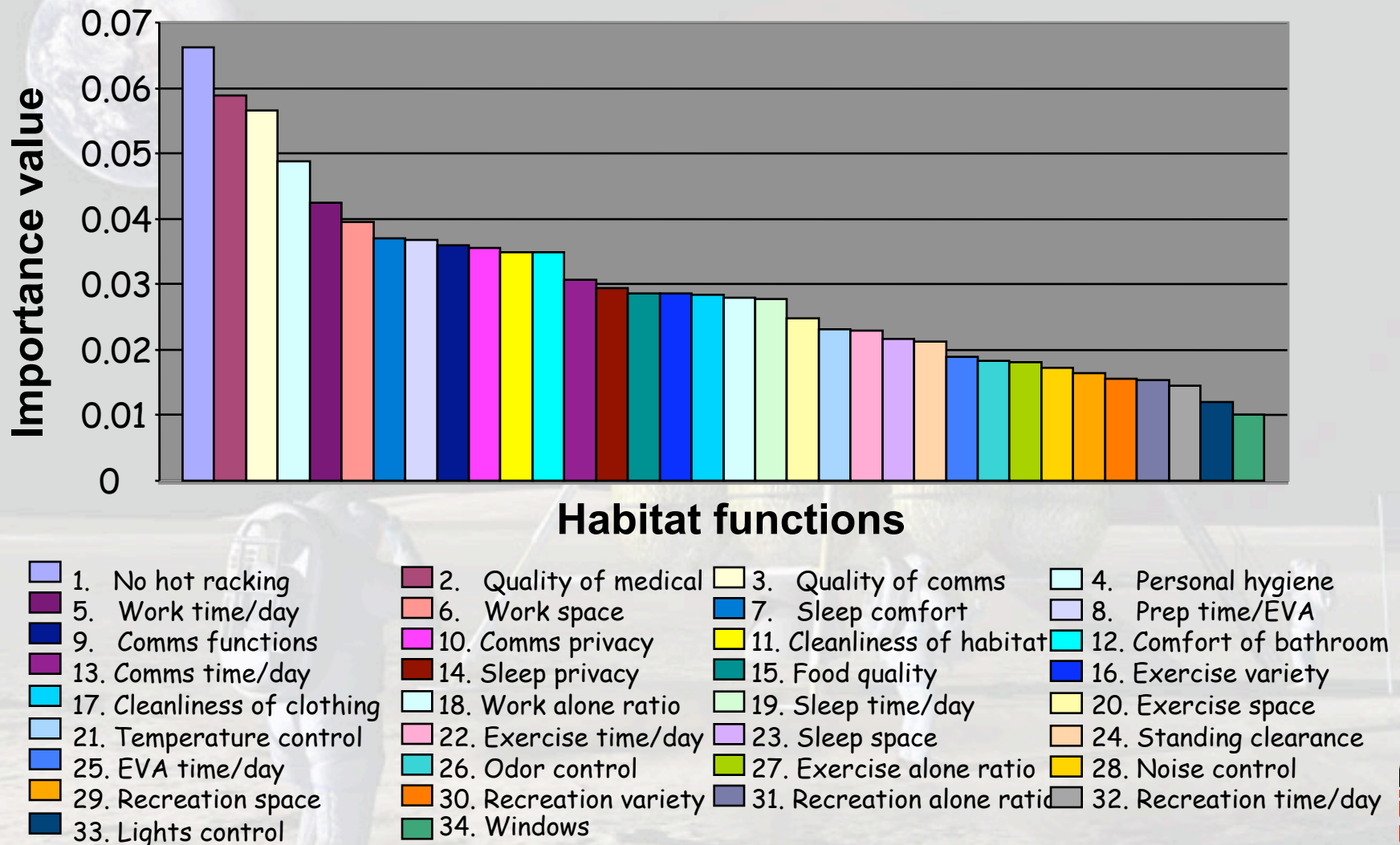
- Subjective survey responses converted to numerical relative importance values and fed into AHP matrices:

“Much less important” =	<b>0.125</b> ( = $2^{-3}$ )
“Moderately less important” =	<b>0.354</b> ( = $2^{-1.5}$ )
“A little less important” =	<b>0.707</b> ( = $2^{-0.5}$ )
“About as important” =	<b>1.000</b> ( = $2^0$ )
“A little more important” =	<b>1.414</b> ( = $2^{0.5}$ )
“Moderately more important” =	<b>2.828</b> ( = $2^{1.5}$ )
“Much more important” =	<b>8.000</b> ( = $2^3$ )

- Remaining matrix elements filled in with reciprocals of conjugate elements
- For each AHP matrix:
  - Importance values of each function or sub-category are the elements of the normalized principal eigenvector
  - “Consistency” is matrix size divided by the principal eigenvalue, with a value of 1 indicating complete consistency
  - function importance values multiplied by importance value of the sub-category
- Overall importance values are the averaged values generated from all respondents, weighted by matrix consistency



# AHP Results: Function Importance Values



# AHP Results: Important Functions

- Hot racking considered unacceptable, the most important function at 2.3 times the average importance value
- Medical facilities, communications connection quality, and personal hygiene round out vital functions
- Work time and space were highly ranked
- Non-physical recreation features considered especially unimportant
- Lighting quality and windows were the least important functions considered, with windows 0.35 times as important as the average function
- The most important function was 6.5 times as important as the least important function





# AHP Results: Consistency and Variation

- Overall matrix consistency: 92.5%
  - Most consistent matrix: “Work space”, at 96.6%
  - Least consistent matrix: “General environmental quality”, at 90.3%
  - Importance value averages are weighted by matrix consistency to improve reliability of results
- Standard deviation and coefficient of variation were computed for each habitat function
  - Average standard deviation was 0.0215, average coefficient of variation was 73.4%
    - Greatest std. dev.: “No hot racking” ( $\sigma = .0645$ ,  $c_v = 97.4\%$ )
    - Greatest coeff. of variation: “Quality of comms” ( $\sigma = .0637$ ,  $c_v = 112.5\%$ )
    - Lowest std. dev.: “Recreation time per day” ( $\sigma = .0066$ ,  $c_v = 45.5\%$ )



# AHP: Demographics and Analysis of Variance

- Respondents:

- By nationality:

- American (15)
    - Italian (11)
    - French (2)
    - Romanian (1)

- By experience:

- Submarine (19)
    - Ship (11)
    - Arctic/Antarctic base (3)
    - Other (2)

- By age group:

- ≤40 years (16)
    - >40 years (13)

Statistically significant variances, at 95% confidence

<u>Demographic set</u>	<u>Feature</u>	<u>Difference from complimentary set</u>
French	EVA time/day	+26.3%
	Exercise alone ratio	-11.9%
American	Quality of comms	-5.3%
Ship crew members	Personal hygiene	+0.9%
	Quality of medical	+1.3%
	Recreation alone-time ratio	-0.8%
	Sleep privacy	+0.3%
Submariners	Bathroom comfort	-0.6%
Age 40+	Comms privacy	-1.4%
	Temperature control	-0.8%

- Performing ANOVA between astronaut and analogue populations can justify the statistical relevance of analogue populations



# Fidelity of analogue environments

- The analogue environments considered in the survey may be of low fidelity, due to several factors:
  - Windows may be less important in environments with a static view/ no external view
  - Affects of reduced gravity on the importance of habitat functions not accounted for
  - Ability to leave environment may impact importance of habitat functions
- Larger samples and samples of the astronaut population would be needed to identify statistical significance of variations between analogue and space environments





# Quality Function Deployment

- Quality Function Deployment (QFD) used to map habitat functions to specific design features, based on subjective assessment of strength of relationship
- Relationship strength multiplied by the importance value of the corresponding habitat function and summed across all habitat functions to yield the importance of a given design feature
- Useful in determining the added value of an extra unit of mass, volume, etc. to a given system or subsystem

- Most important design features:

- Amount of volume available for activities and privacy
- Sufficient electrical power and data rate for high-functioning communications
- Running water

		Design features
AHP habitat Functions	Habitat function importance values	Relationship matrix
		Design feature importance values



# QFD Implementation

Design feature		Direction of improvement:		Strength of relationship between design feature and AHP function:		empty cell = no relationship		1 = weakly related		3 = moderately related		9 = strongly related	
		▲ = increasing, or binary-desirable	▼ = decreasing, or binary-undesirable	● = target value	▲ = increasing, or binary-desirable	▼ = decreasing, or binary-undesirable	● = target value	1 = weakly related	3 = moderately related	9 = strongly related	1 = weakly related	3 = moderately related	9 = strongly related
AHP Function / weight													
Cleanliness of hab	0.035283	5											
Personal Hygiene	0.04989												
Comfort of bathroom	0.034159												
Quality of medical	0.058776												
Cleanliness of clothing	0.02801												
Comms features	0.0356												
Comms time/d	0.030345												
Comms privacy	0.035341												
Quality of comms	0.05731												
Lights control	0.011869												
Noise control	0.01679												
Windows	0.009841												
Odor control	0.018986												
Temperature control	0.02369												
Standing clearance	0.00748												
Food quality	0.02875												
Rec space	0.016397												
Rec variety	0.015041												
Exercise space	0.024372												
Exercise variety	0.028617												
Exercise alone ratio	0.018572												
Work space	0.039183												
Prep time/EVA	0.037124												
Work alone ratio	0.028												
Sleep space	0.021376												
Sleep privacy	0.029328												
Sleep comfort, physical	0.037386												
No hot racking	0.067572												
Total importance	0.858341												



# QFD Results: First 20 Design Features

Rank	Design feature	Importance value	Rank	Design feature	Importance value
1	Total habitable volume	1.823	11	Total noise	0.677
2	Electrical power	1.589	12	Heat removal rate	0.660
3	Running water	1.460	13	Ventilation rate	0.642
4	Particle/odor/microorganism filtration	1.314	14	No hot racking	0.608
5	Earth downlink data-rate	1.296	15	Communications features	0.578
6	Humidity	1.074	16	Volume re-allocate-able for medical use	0.529
7	Closed loop water	1.066	17	Complexity of first-aid	0.529
8	Frequency of clothing changes	0.925	18	Medical sensors/diagnostic equip.	0.529
9	Accessible storage volume	0.845	19	Sponge bath vs. shower	0.518
10	Number of controllable lighting zones	0.681	20	Communications quality	0.516





# MDRS Crew 73 – 12/27/08-1/2/09



- Unscheduled target of opportunity to collect data on space usage and personnel flows in confined environments. (Thanks to Heather Bradshaw and the Mars Society.)
- Two compact digital cameras used to:
  - Acquire an 800x600 pixel frame when motion is detected
  - Typical sequence rate 2 sec/frame
- Acquired more than 100,000 frames over one week.
- Final goal: Collect data to optimize relative locations of functional spaces
- Results will be published at ICES 2009



# Virtual Reality Testing and Validation

- Use immersive 3D environment (head-mounted display with head and hand motion tracking, and fly-through navigation control) to analyze habitat designs with stereoscopic vision and 1:1 scaling
- Primarily interested in work envelopes, to optimize size, shape, and usage demands on crew spaces





# Virtual Reality Testing and Validation

- Software:
  - Dassault Systems CATIA V5R18
  - Nvidia stereo drivers
- Hardware:
  - Stereoscopic Head Mounted Display – eMagin Z800 3D Visor
    - OLED microdisplays
    - Field of view: 40° (diagonal)
    - Resolution: 800 × 600
    - Refresh rate: 60 Hz
    - 100% eye overlap
    - Stereoscopy: page flipping



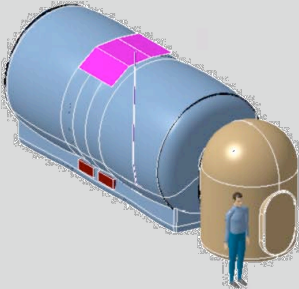
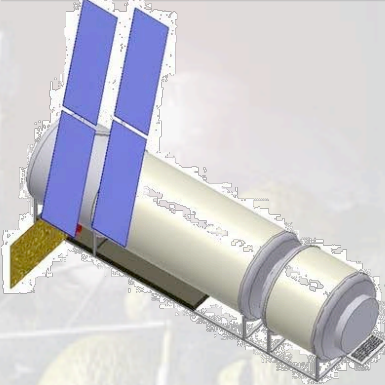



# Design Space Subdivision

- Three separate teams were tasked to independently develop three preliminary point designs
- Individual design requirements were differentiated by mission profiles and support infrastructure
- Common Requirements:
  - Crew : 4
  - Provide basic life support (crew survival)
  - Mission duration : 28 days



# Design Space Subdivision

<p>Concepts</p> 	<p>Lunar Puptent</p>	<p>Winnebago</p> 	<p>Igloo</p> 
<p>Available Systems</p>	<p>None</p>	<p>Altair Lander</p>	<p>Outpost</p>
<p>Purpose</p>	<p>Standalone Contingency</p>	<p>Initial Exploration Outpost Expansion</p>	<p>Extended Crew (+4) Outpost Dependent</p>



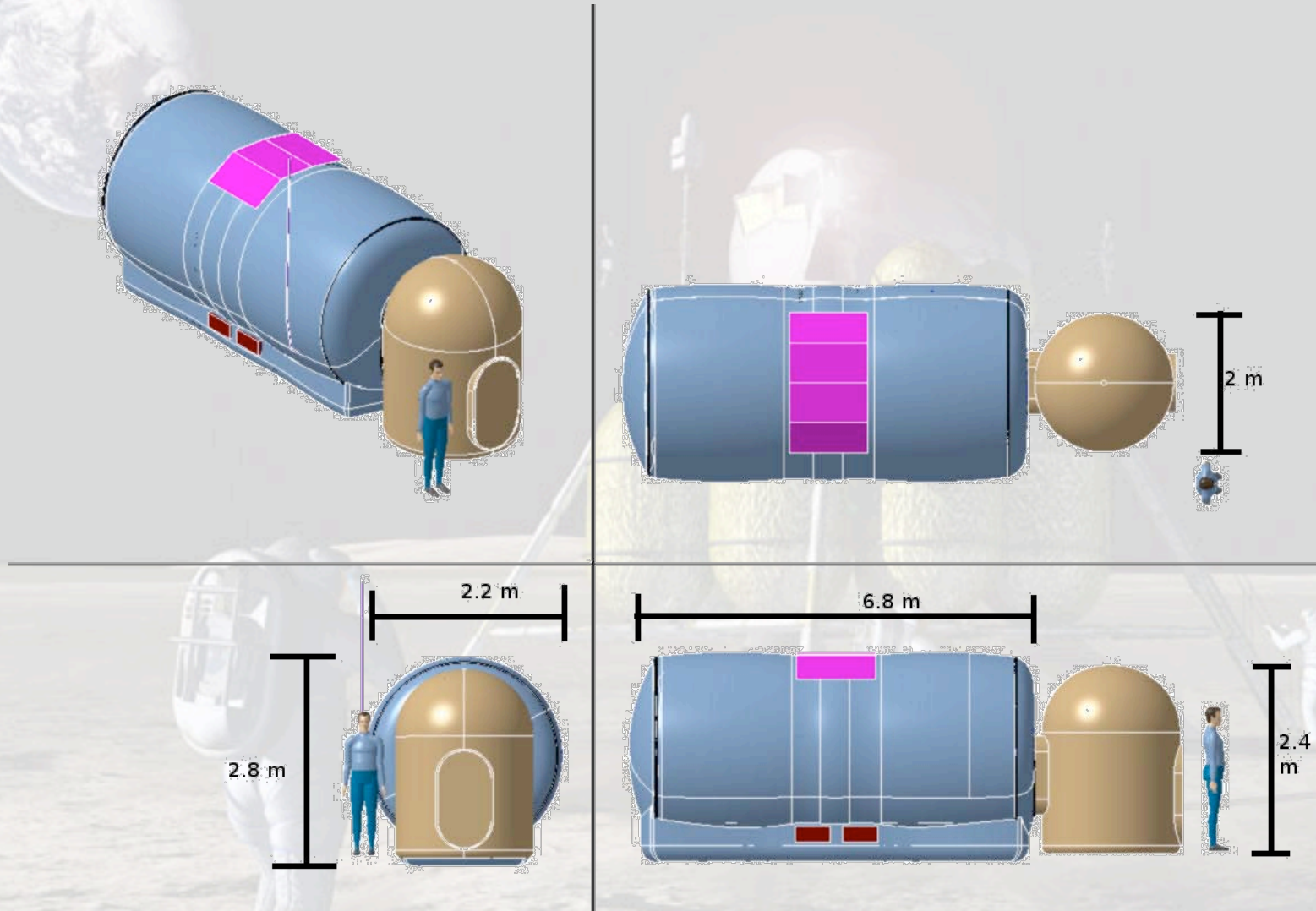
# The Lunar Pup-Tent

- Mission Profile:
  - The lunar pup tent has been designed to minimize storage volume and mass
  - Provides for crew survival while waiting for a rescue mission from either an outpost-based or Earth-based crew
- Top Level Requirements
  - Meet basic needs (air, water, food, exercise, thermal and radiation protection) to a crew of four for 28 days (stand-alone)
  - No redundant systems (and therefore no +30 day contingency)
  - EVAs will be limited to habitat entry and evacuation
  - Must self-deploy

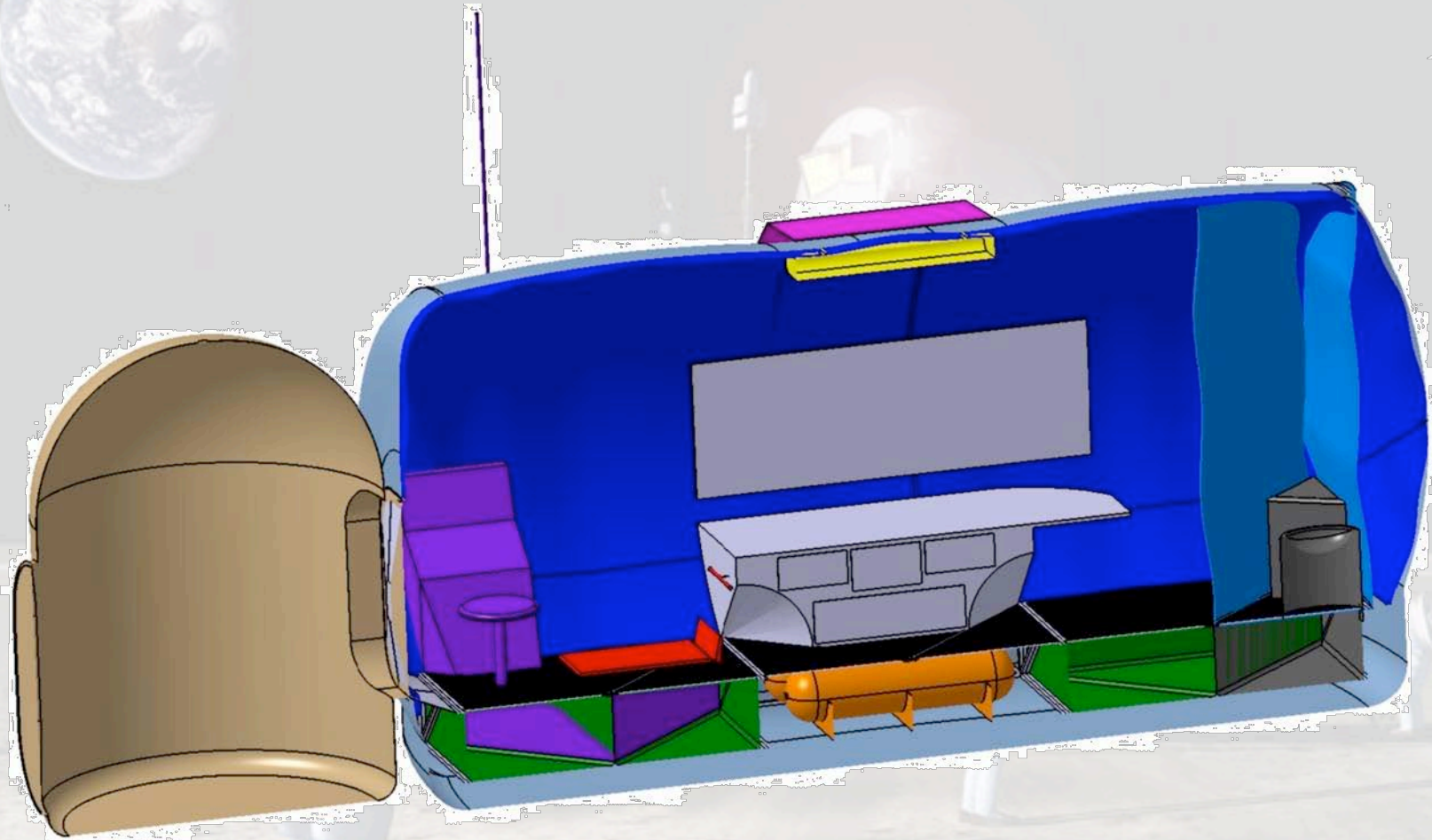




# Exterior View



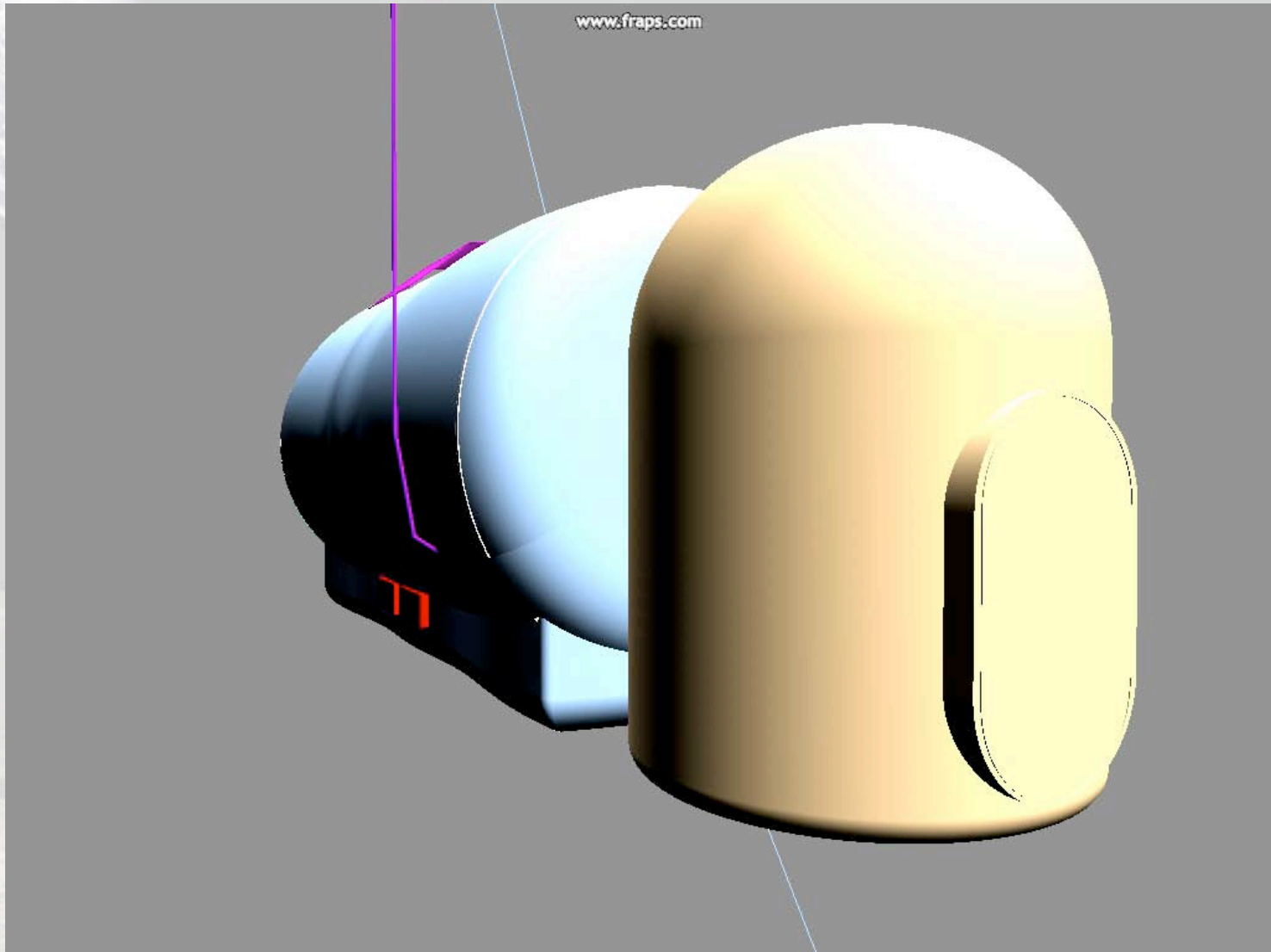
# Interiors



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# VR Walkthrough

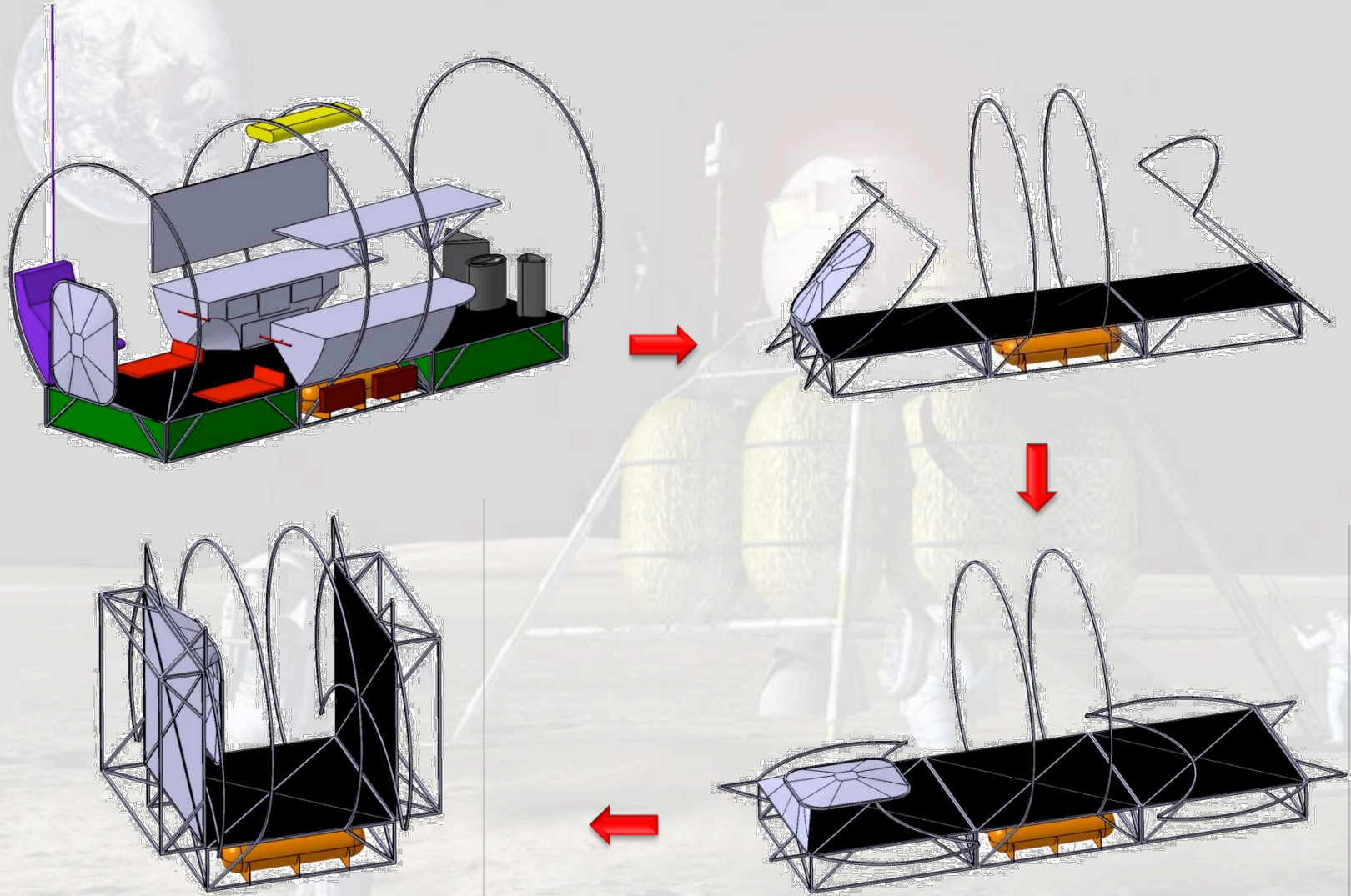


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# Collapsible Structure



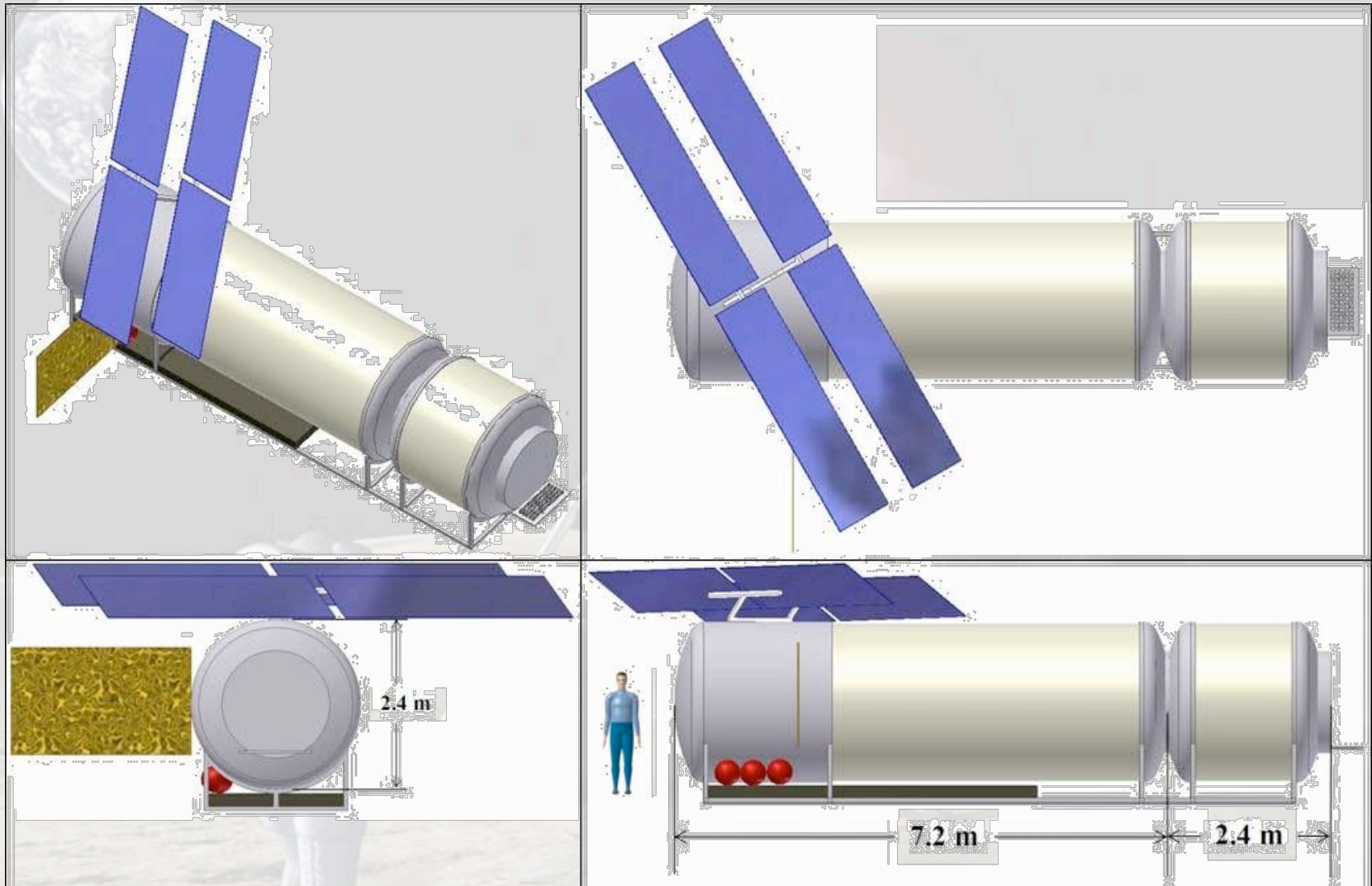
# The Winnebago

- Mission Profile:
  - 28 days, 4 crew
  - Habitat element supported by one Altair lander
    - Designed to operate independently of Constellation outpost architecture
    - Can be adapted and expanded to fill a role as part of an outpost
    - Partially inflatable hybrid structure
- Top Level Requirements:
  - Provide for crew functionality for 28-day mission with a minimum of resources
  - Not a contingency scenario, can require in-situ preparation



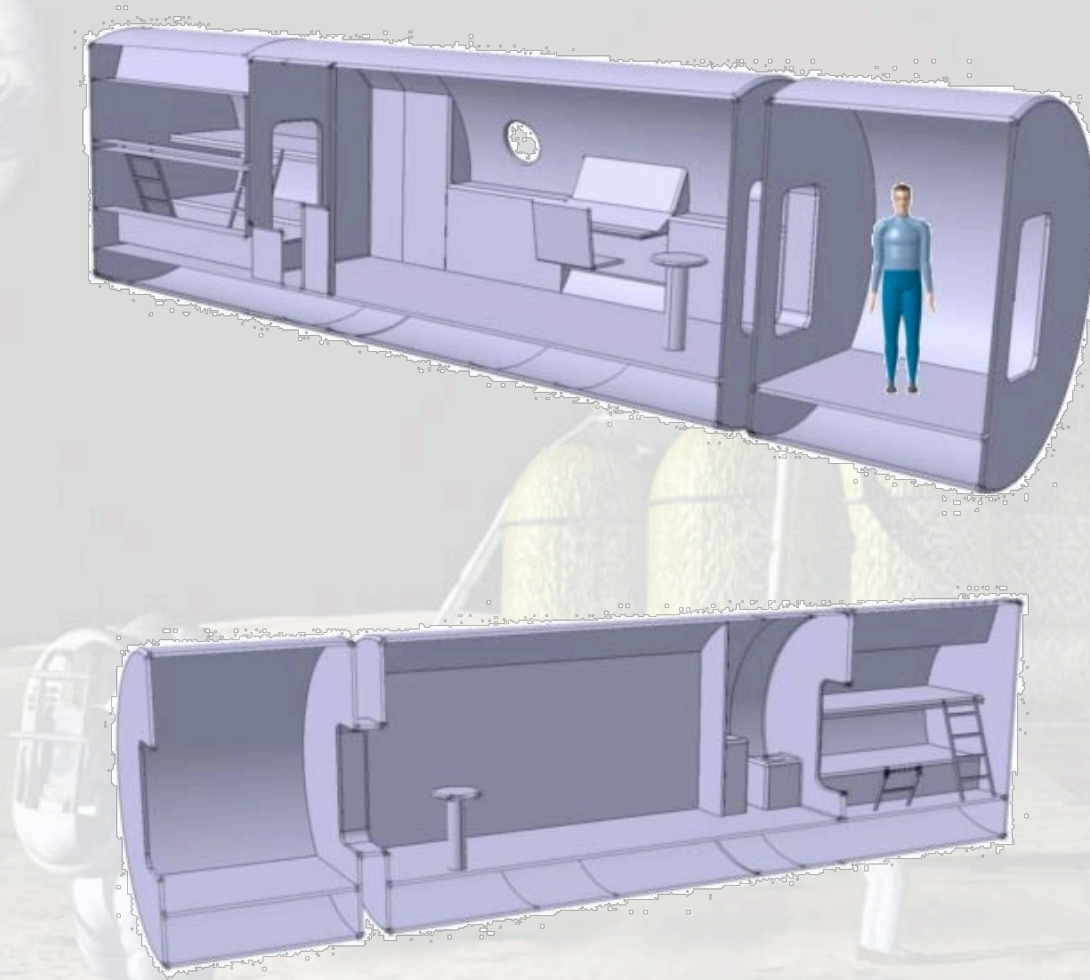


# Exterior View

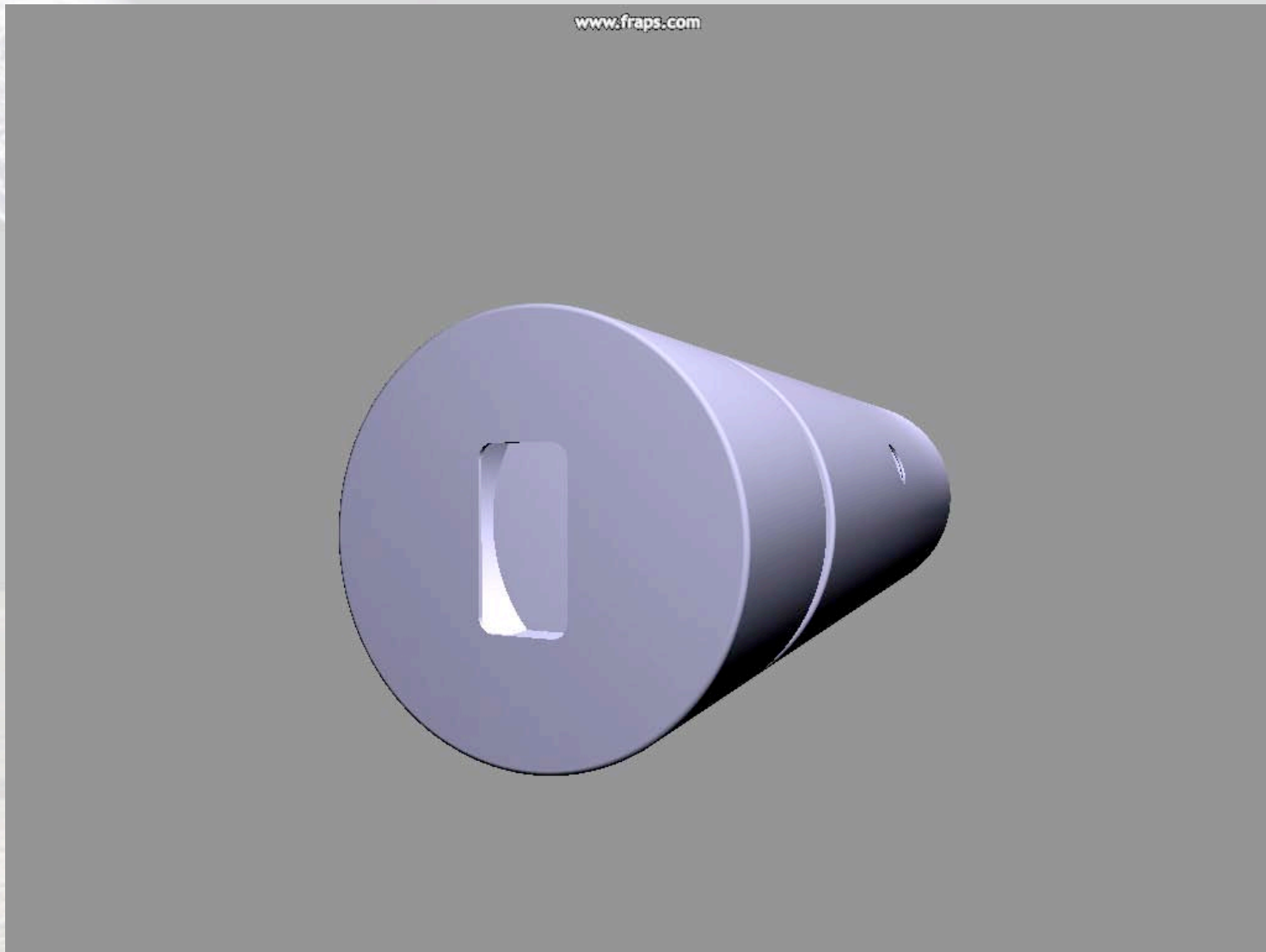




# Interiors



# VR Walkthrough



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# The Igloo

- Mission Profile:

- Provide a Minimum Functional Habitat addition to the ESMD design
- MFH can be used as a secondary or emergency shelter
- Increase ESMD outpost total crew size to 8 for a one month mission

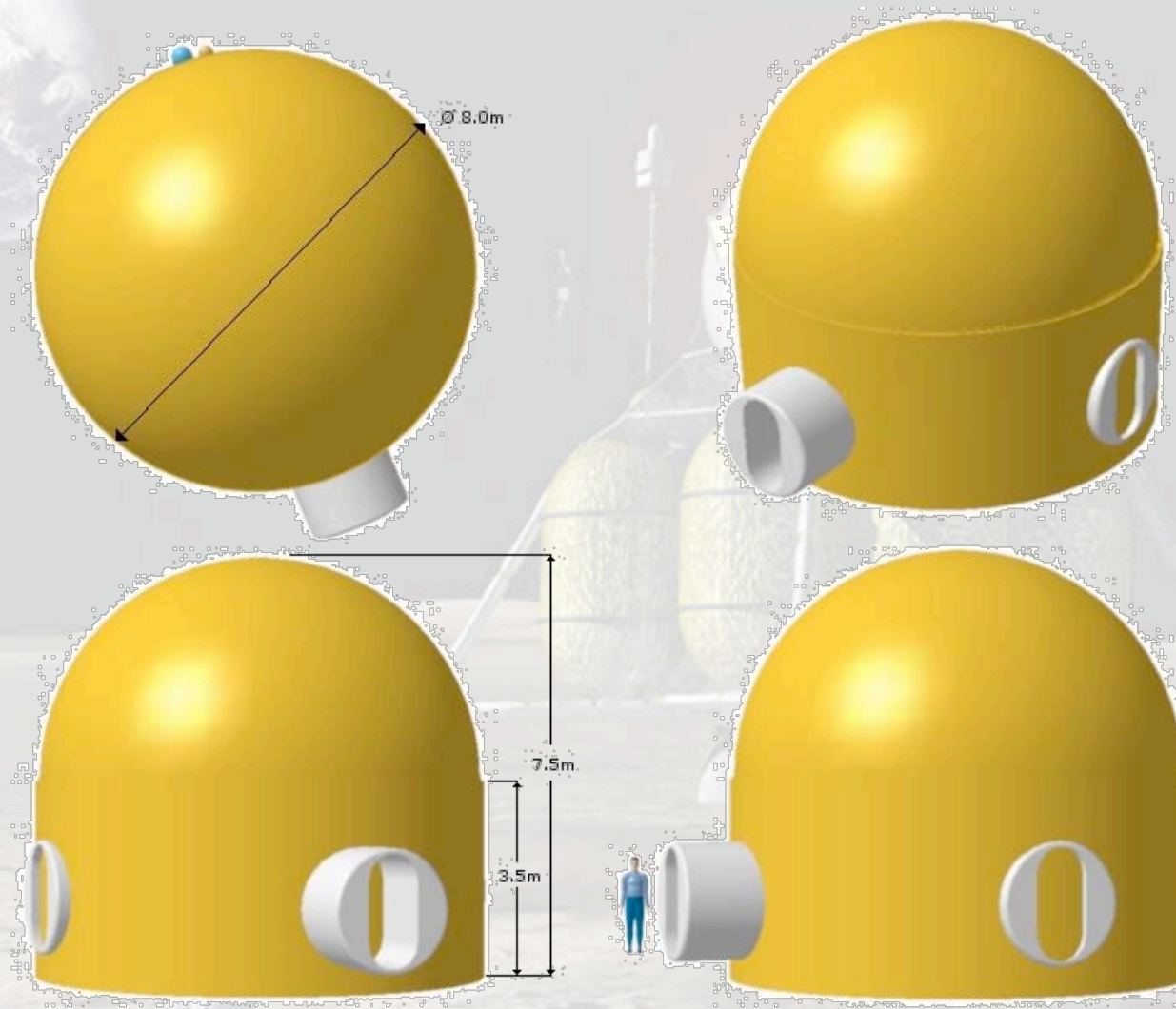
- Requirements/Assumptions

- Main outpost provides:
  - GCR and SPE shielding
  - Communications / Avionics
  - Power
- Outpost location: south pole
- In-Situ Resource Utilization
- Habitat shall provide:
  - Thermal control
  - Power back-up
  - Food/medical and other supplies for 58 days
    - 28-day mission
    - 30-day contingency
  - Airlock
  - ECLSS





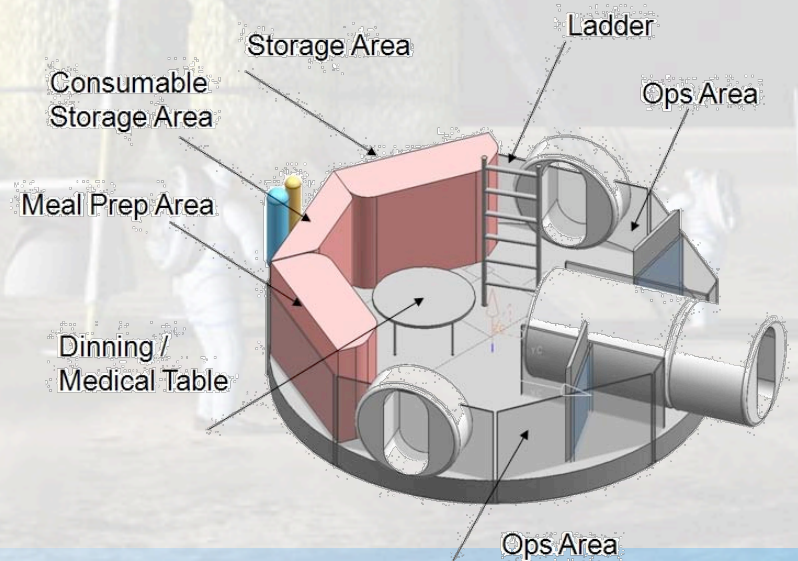
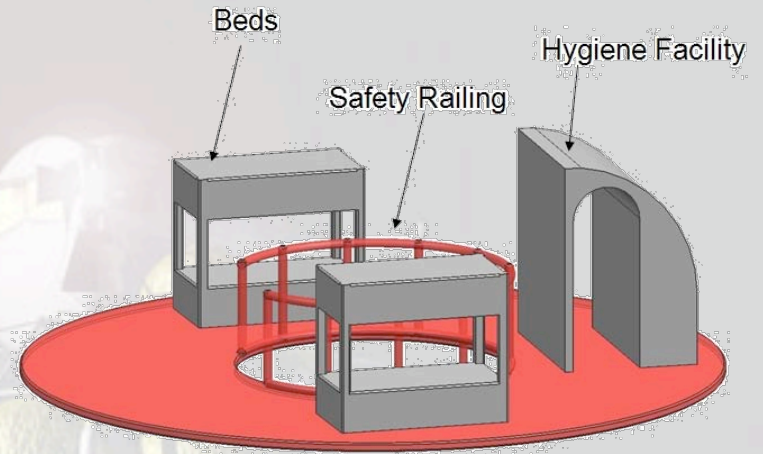
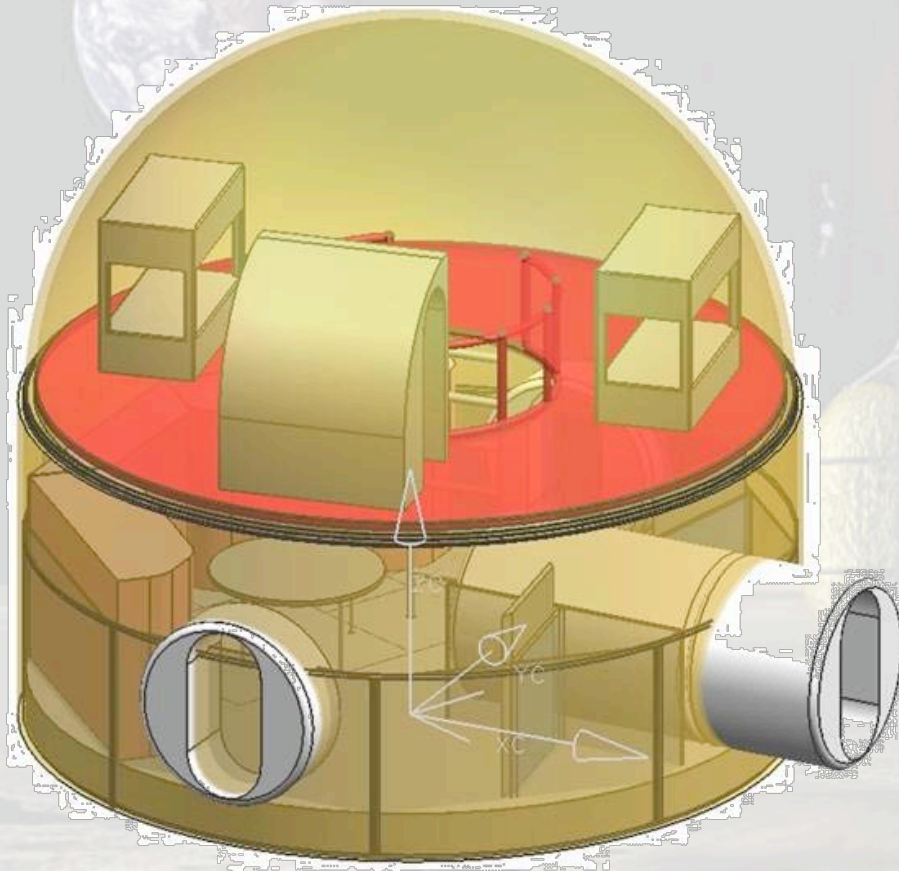
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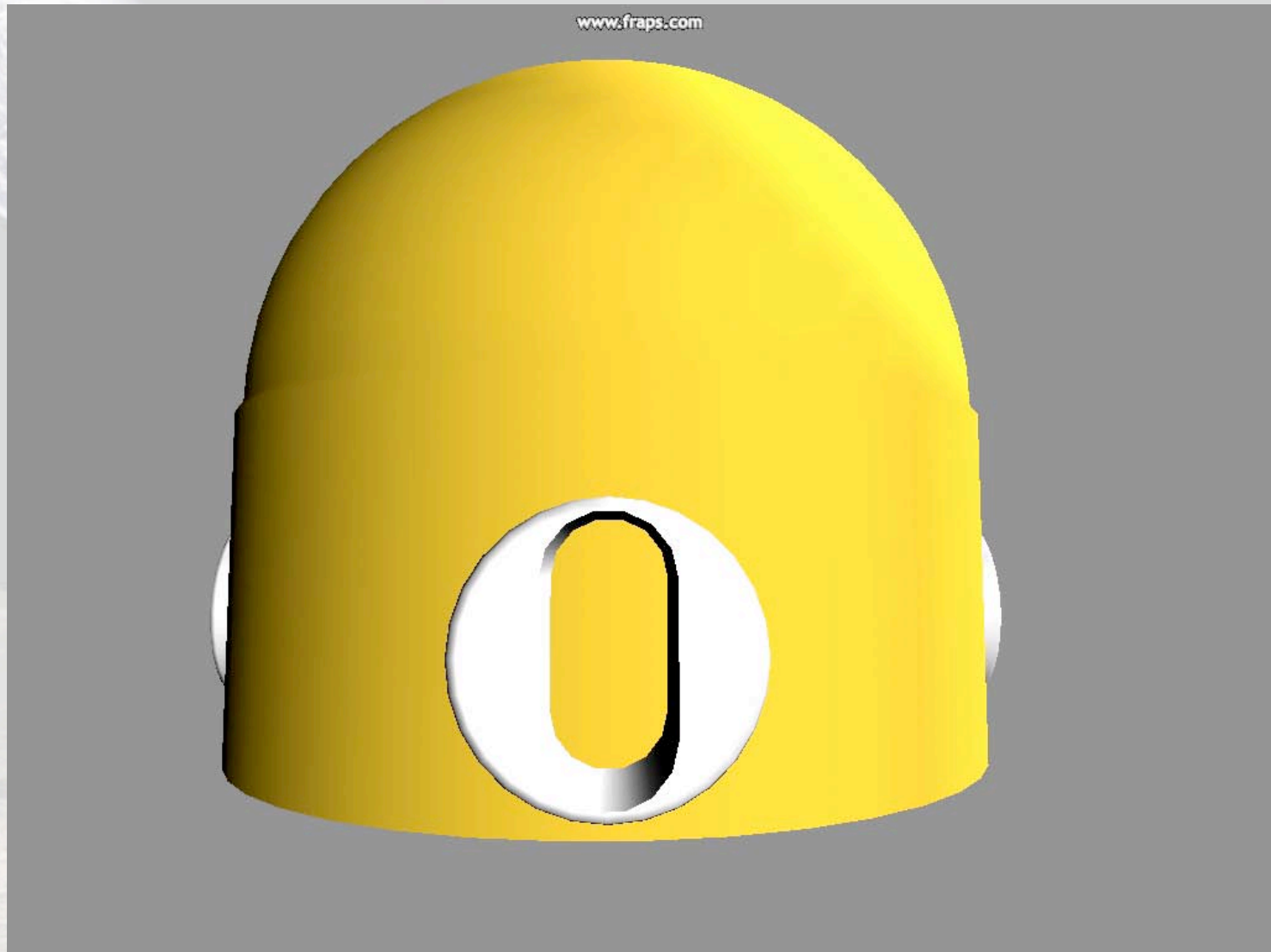
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# Interiors



# VR Walkthrough



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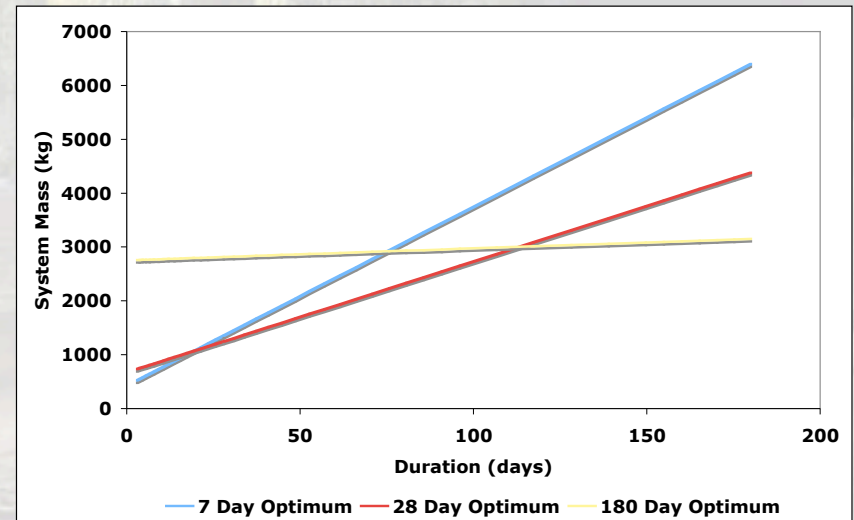
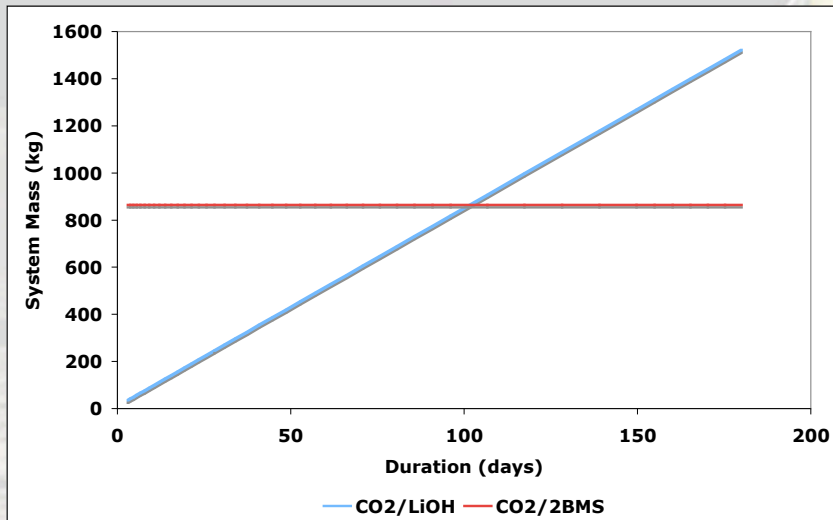
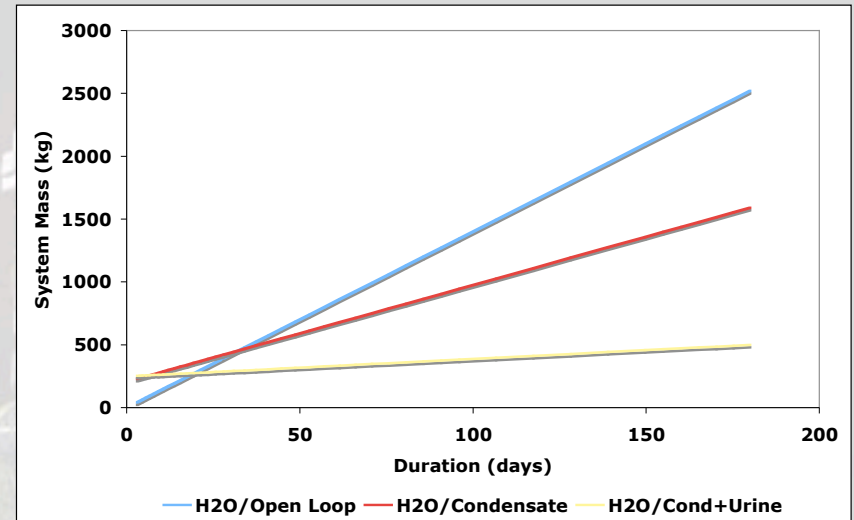
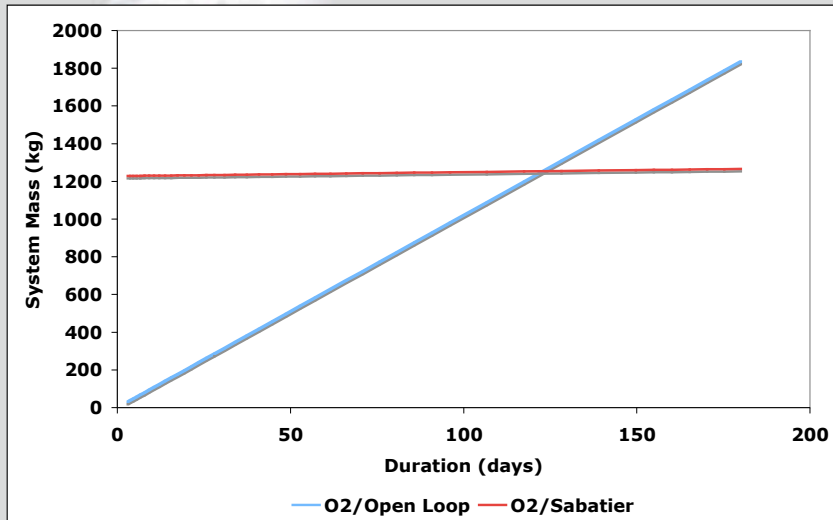


# Lessons Learned

- VR is a useful tool for rapid evaluation of concepts
- Accurate registration in the head tracking is fundamental
- Models must be very detailed in order to give a feel for the environment
- Simultaneous hand tracking is a very desirable feature
- Horizontal cylinders give a sense of tunnel vision
- Vertical cylinders allow for better floor space usage, but provide less wall area
- In vertical cylinders, vertical ladder should not be located in the center of the floor space

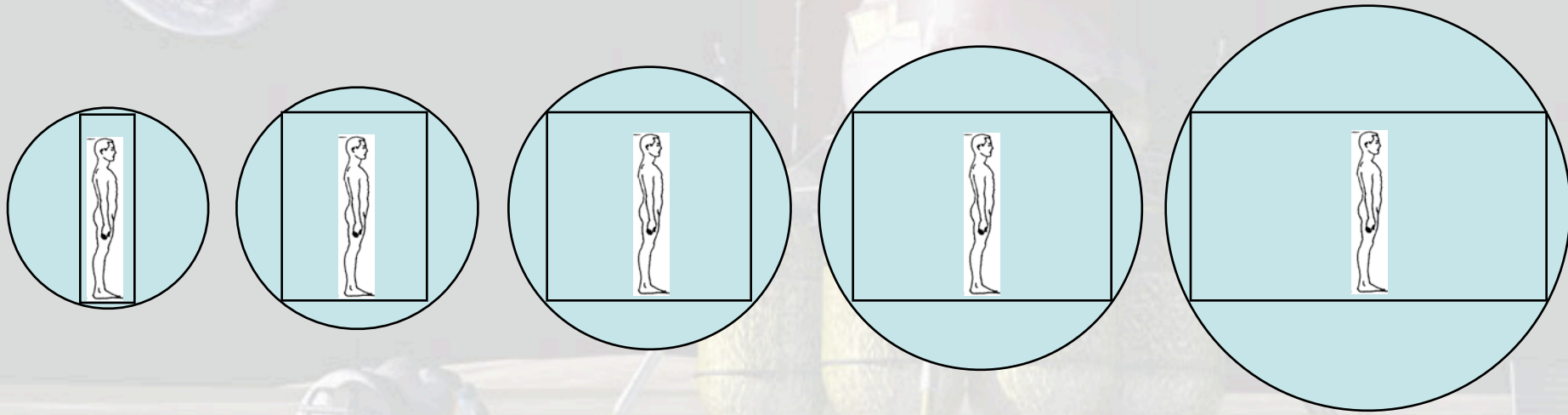


# Parametric Life Support Trades



# Habitat Layout - Vertical or Horizontal?

- Geometric modeling of “packing factor” to fit humans into cylindrical shapes



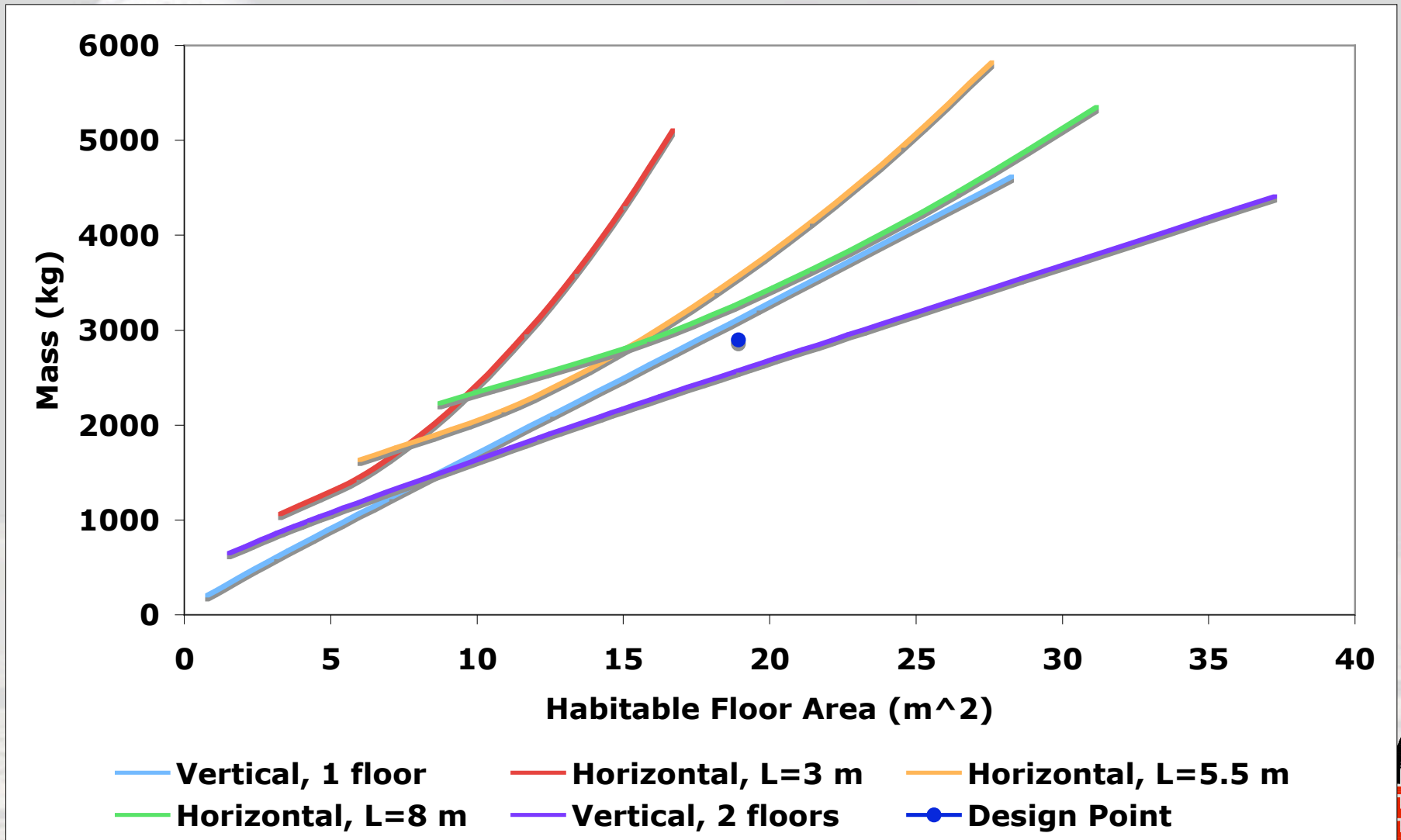
- Mass estimation for human-rated pressurized volumes from JSC-26096 (converted to metric)

$$M < kg > = 13.94 \left( A_{surface} < m^2 > \right)^{1.15}$$

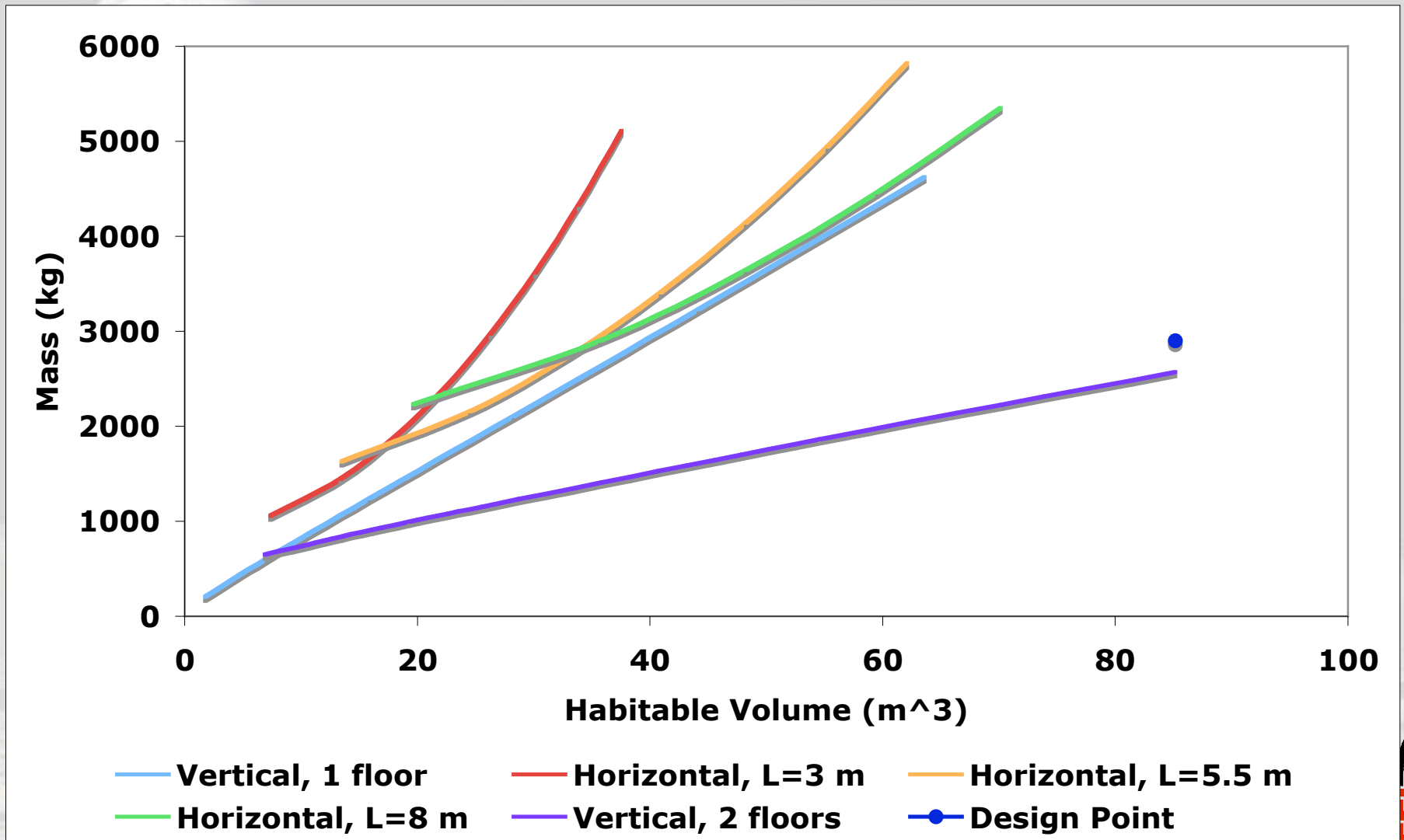




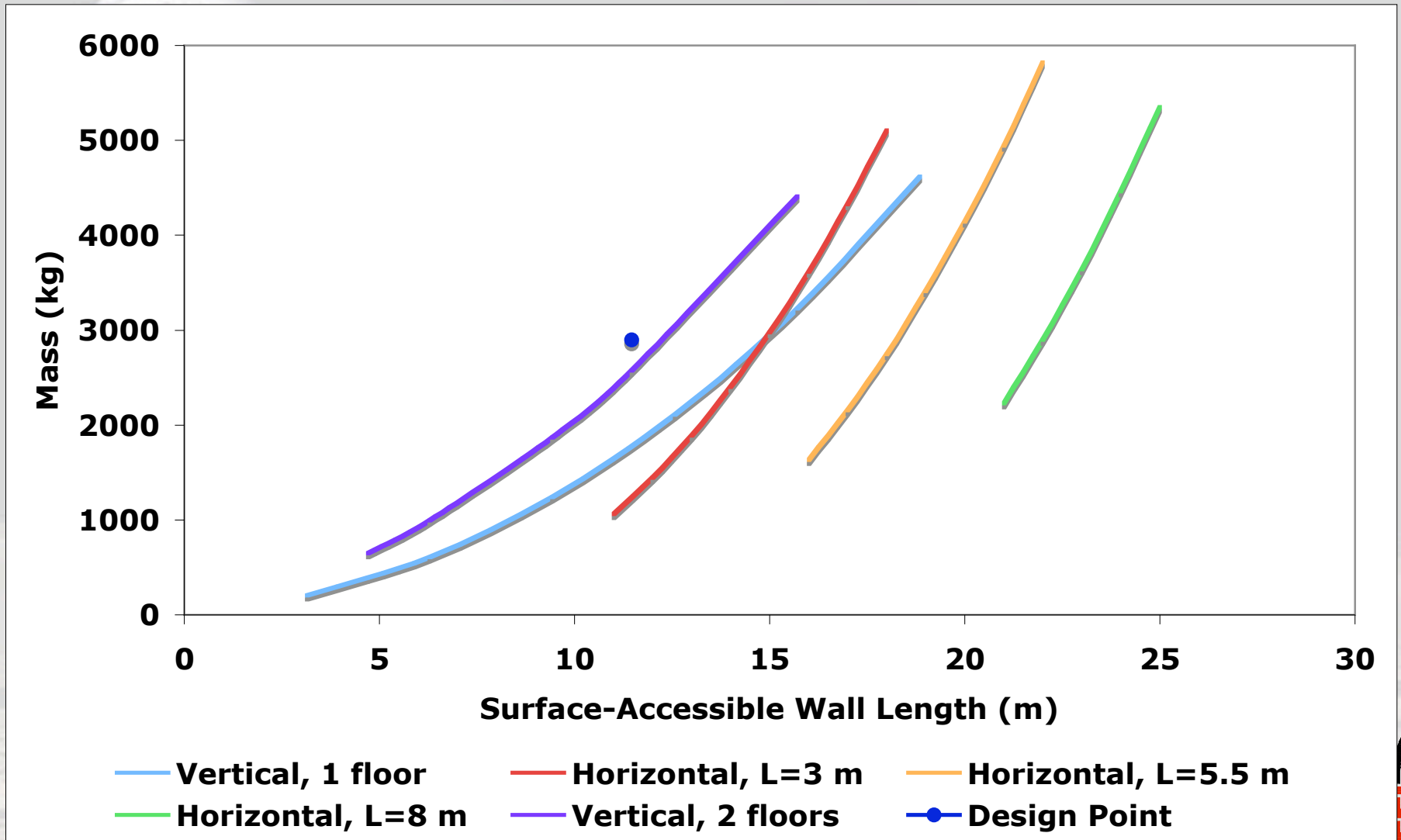
# Habitat Layout Trades - Floor Area



# Habitat Layout Trades - Useful Volume

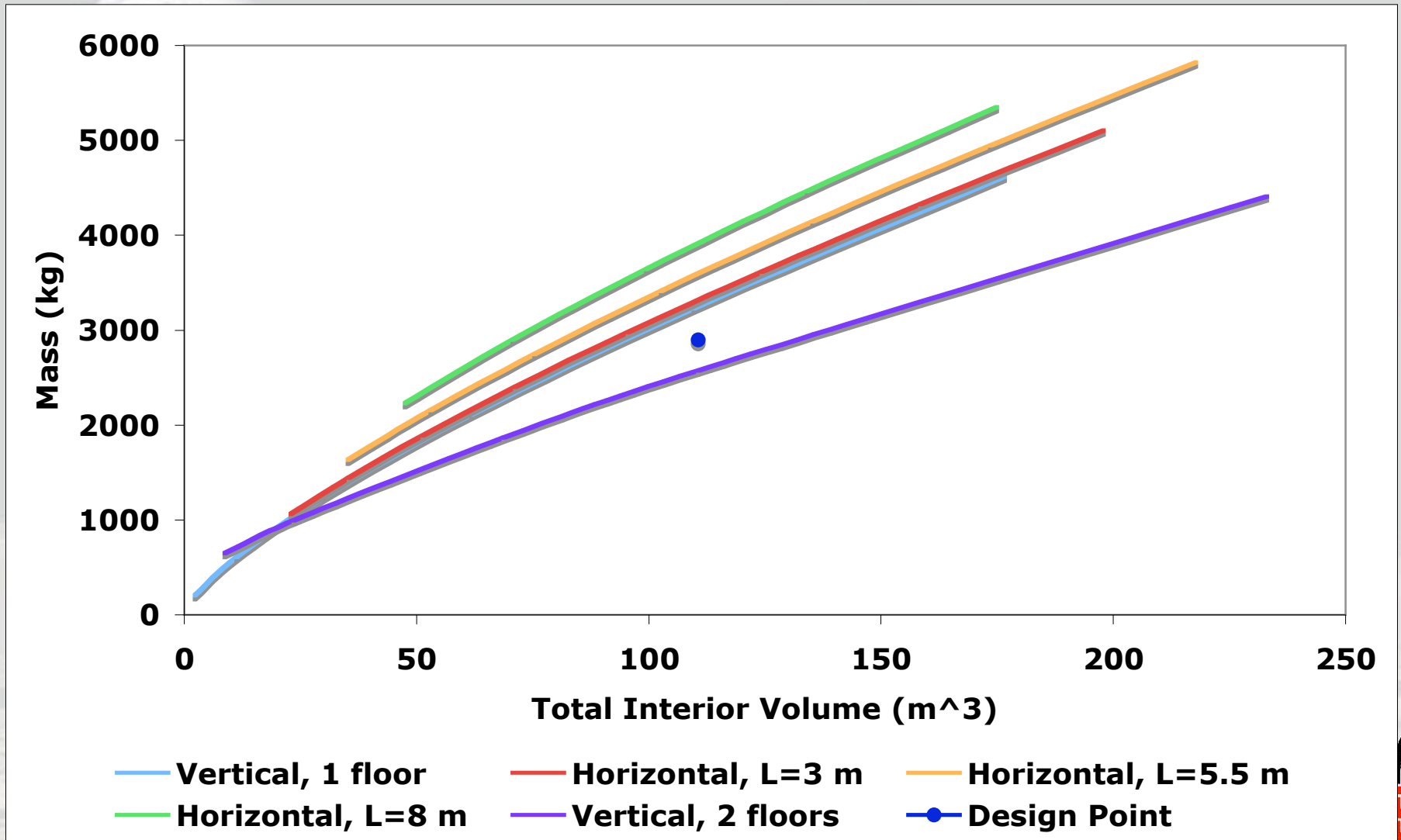


# Habitat Layout Trades - Accessible Wall





# Habitat Layout Trades - Total Volume



# Conclusions From Trades and Designs

- Minimum functional habitat is feasible across the spectrum of possible designs
  - Inflatable
  - Horizontal cylinder
  - Vertical cylinder
- An MFH which meets the mass limitations of this study will be quite small
- Multilayer vertical configuration (clearly favored by parametric analysis) has much less design background (other than colonization concepts)
- Significant utility to a full-scale mockup for evaluation



# Full-Scale Mockup Design

- Availability of fiberglass tank in size range of interest
  - 3.65 m diameter x 3.3 m tall
  - Open top required some simple and quick approach to weatherproofing
  - Total time available for mockup = 2 weeks
- Internal layout and surface area
  - Vertical cylinder with two decks
  - Approximate surface area: 30 m<sup>2</sup>
  - Separate functional areas as much as possible





# ECLIPSE Mockup – Main Structure



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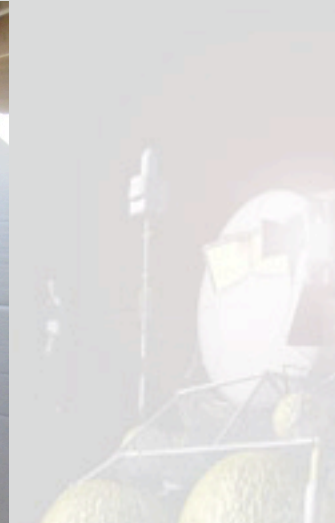
# ECLIPSE Mockup – Main Structure



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# ECLIPSE Mockup - Interiors



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# ECLIPSE Mockup - Interiors



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# Testing: ECLIPSE Crew 1

- Technical mission for preliminary habitat evaluation and systems testing
  - Crew: 4
  - Duration: ~40 hrs
- Failures summary:
  - T-2h: Water distribution systems leaks and absence of spare parts doesn't allow for repairs
  - T+0 (2:34 a.m. of Feb 5<sup>th</sup>): Hatch closed
  - T+5 min.: First failure (electrical system malfunction)
  - T+10 min.: electrical system repaired





# ECLIPSE Crew 1



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# Lessons Learned from Mockup

- A two floor design must accommodate for easy package transport between floors
- Avoid using beds/bunks for seating space
- Include a table in the living quarters; otherwise move food preparation to operations area
- Must have a source of drinkable water on each floor
- Must redesign bunks in order to better interface with the dome (and therefore waste less space)
- Trash accumulates quickly and requires air tight storage or disposal space.
- Bathroom privacy and comfort is not easy to obtain in such environment

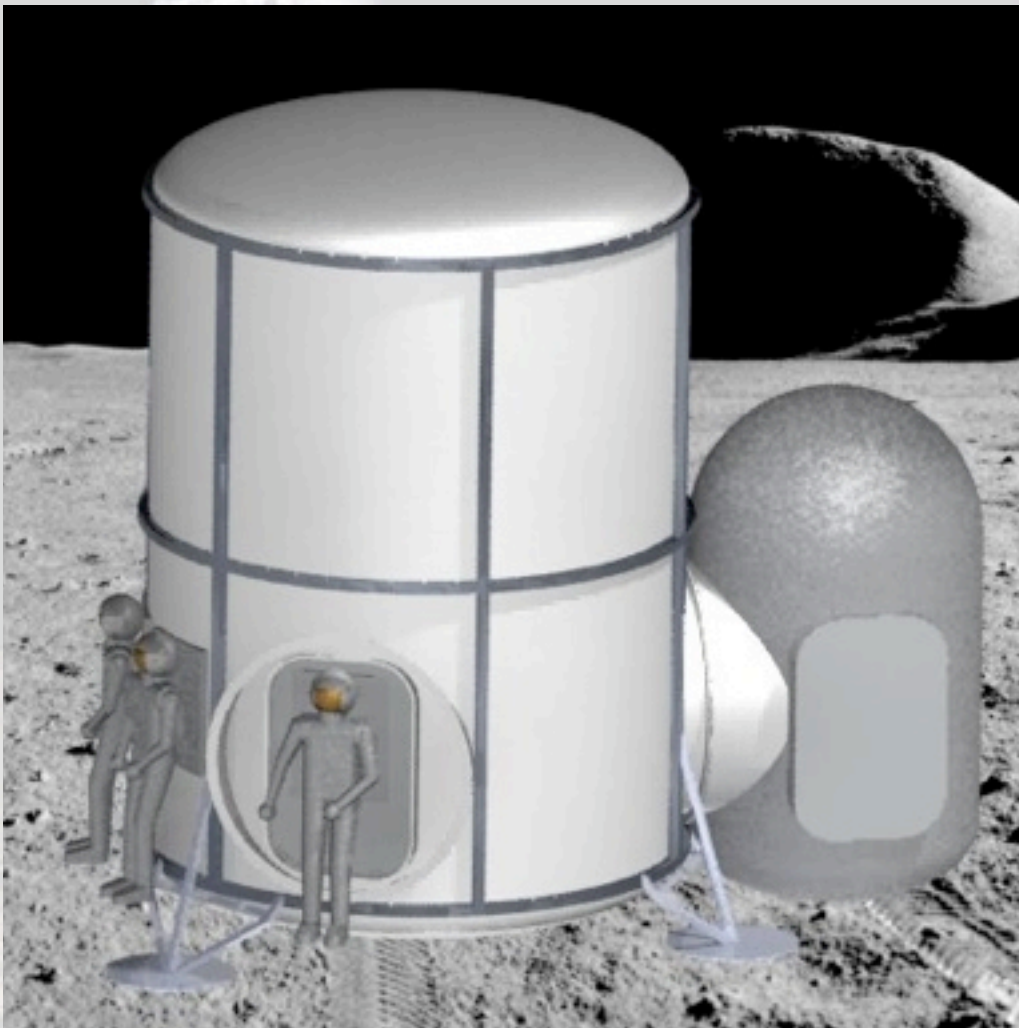


# Development of Final Design

- Synthesis from preliminary designs, trade studies, virtual reality, and full-scale mockup tended to
  - 3.65 m diameter
  - Two full-diameter levels
  - Separation of operations and habitation functions
- Operational assumptions
  - Four suitports for nominal ops plus inflatable airlock
  - Premium on stowage, multipurpose space, functionality
- Design to MFH specifications for outpost; examine options in both growth (multihabitat) and isolated (self-sufficient habitat) directions



# UMd Final MFH Design

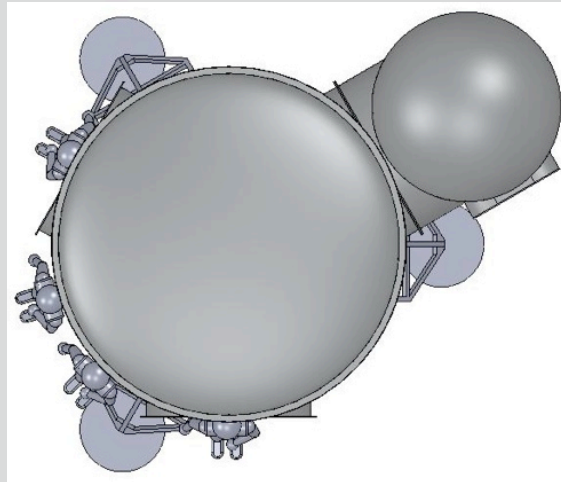


- 3.65 m diameter
- 5.5 m tall
- 4:1 ellipsoidal endcaps
- Three module berthing ports (Cx standard)
- Four suitports (two in berthing hatches)
- Inflatable airlock
- All 6063-T6 structure

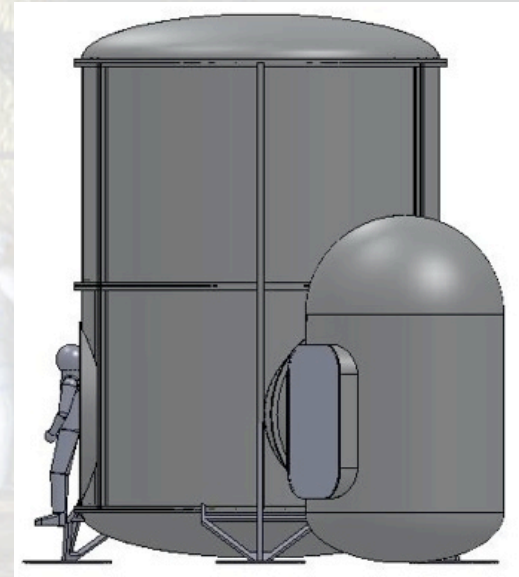
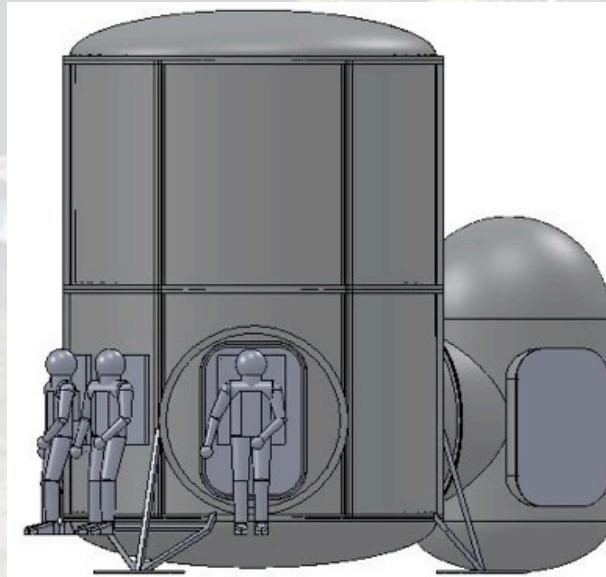
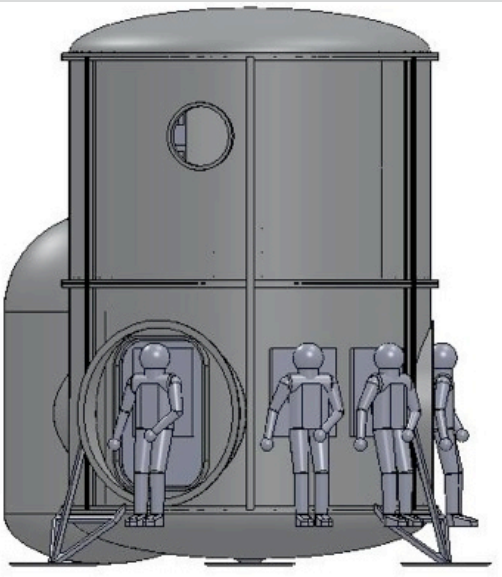




# Habitat Orthogonal Views



3.65 m



5.5 m



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# Lower Deck Layout

CTB Stowage Racks

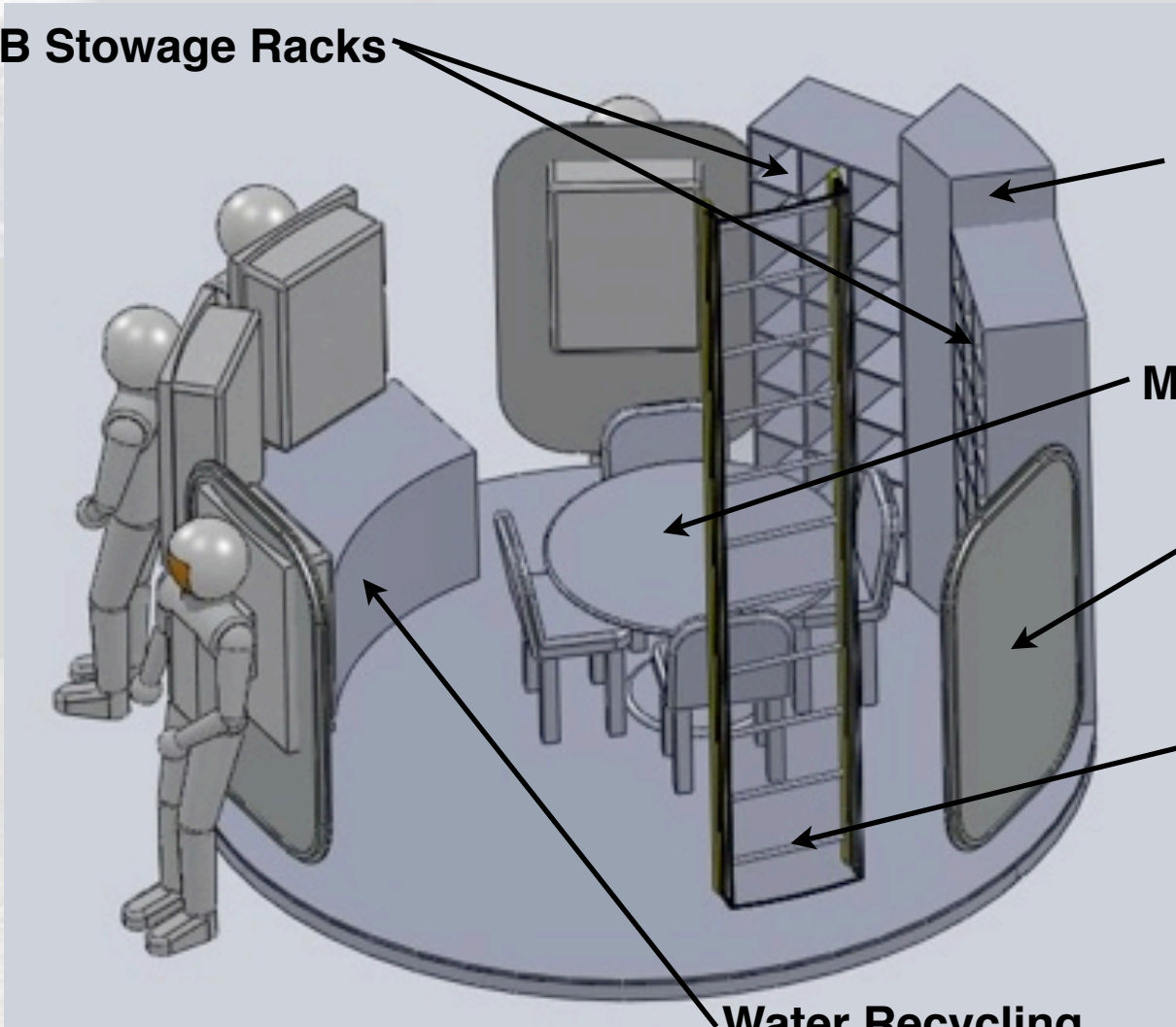
Air Handling/  
CO<sub>2</sub> Scrubbing/  
Heat Exchanger

Multipurpose Table

Berthing Hatch

Ladder to  
Upper Deck

Water Recycling



# Upper Deck Layout

Individual Crew Berths

Galley Wall -  
Food Preparation

Table and Seats  
Opened for Meals;  
Stowed Otherwise

Bathroom

CTB Stowage Racks

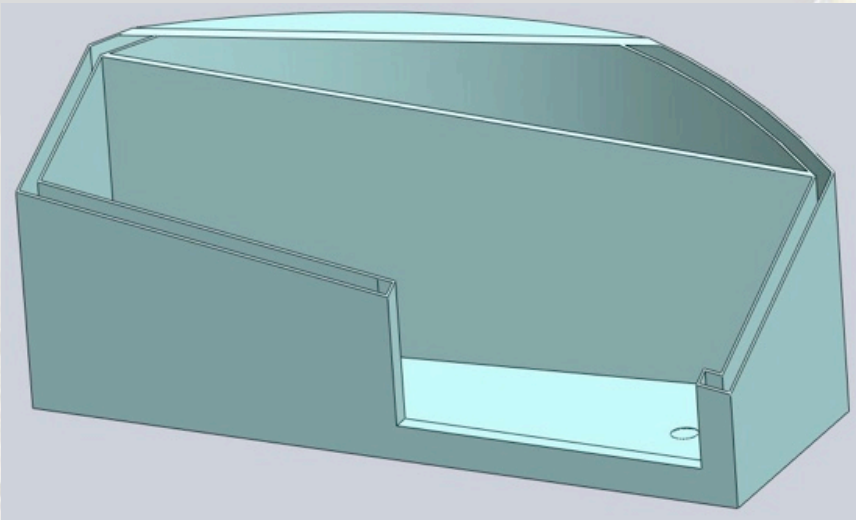
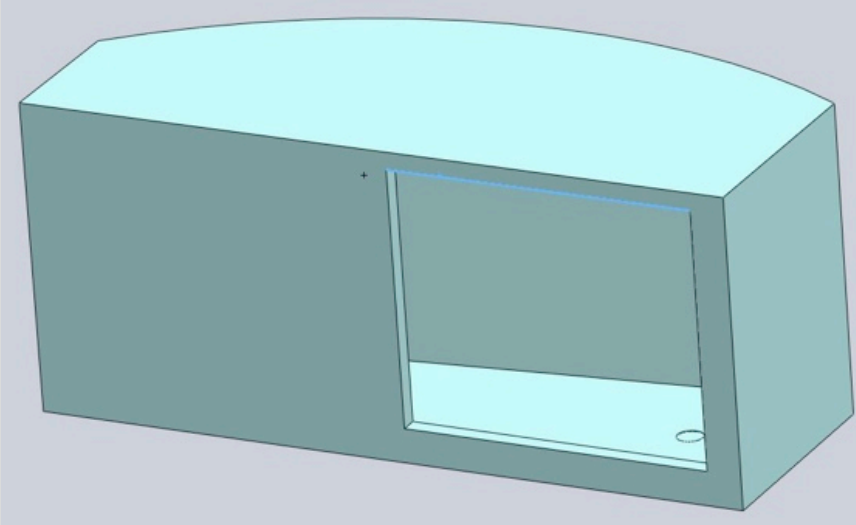


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# Crew Berths



- Personal sleeping berths
- Individual stowage for 6 CTBs and 0.24 m<sup>3</sup> of loose gear
- Water wall - 215 kg of water provides 5 gm/cm<sup>2</sup> radiation shielding (polyethylene door not shown)
- Contingency waste management for 48 hours



# Life Support Systems

- MOS CO<sub>2</sub> scrubbers
  - Recharge for suit PLSS systems
  - Commonality with suit units
  - Growth: Sabatier reactor for O<sub>2</sub> recovery
- Vacuum compression distillation (VCD) for water recovery
  - Recycles wash water, urine
  - No plans to recover water from feces (waste collection tank in lower dome)



# Avionics

“It’s not a spacecraft, it’s a house!”

– Dr. Gary Noyes, Oceaneering Space Systems

- Communications handled by Constellation Lunar Communications Terminal (LCT)
- Life support systems operated by embedded industrial controllers
- 801.11n (equivalent) wireless routers
  - Command and control/systems monitoring
  - Voice over IP
  - Video routing



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# Power Management and Distribution

- Power generation by Cx Mobile Power Unit (MPU)
- 28VDC distribution
- Copper lines to wall plugs/hardwired systems
  - Lower deck
    - 4x suitports (PLSS recharge)
    - Water reclamation systems
    - Air reclamation systems
    - Overhead truss (power drop to general purpose table, lights)
    - Airlock
  - Upper deck
    - 4x berths
    - Kitchen wall (oven, lights)
    - Bathroom
    - Wardroom table



# Thermal Systems

- Heat exchanger between cabin air and water/glycol loop
- Integrated thermal/micrometeoroid shields (TMS) over upper dome, each of six wall segments around upper deck - each segment selectable
- Aeroglaze A276 paint on TMS panels
- MLI between TMS panels and pressure hull
- Nominal heat balance at 22°C requires dome and two upper wall segments
- System operational with loss of dome or any two wall segments



# Mass Estimates - Structure

Element	Mass (kg)
Upper dome	404
Upper cylinder	934
Lower cylinder	957
Lower dome	404
External structure	118
Floor structures	207
Stabilizer legs	272
Hatches	91
Inflatable airlock	68
<b>Totals</b>	<b>3455</b>





# Mass Estimates - Crew Accommodations

Element	Mass (kg)
CTB racks	36
Equipment enclosures	27
Furniture	23
<b>Level 1 Total</b>	<b>86</b>
Waste collection module	68
Berths	278
Table	14
Galley wall	91
<b>Level 2 Total</b>	<b>451</b>
<b>Overall Total</b>	<b>537</b>



# Mass Estimates - Life Support

Element	Mass (kg)
Air handling	23
CO2 scrubbing (MOS)	64
Water recycling (VCD)	57
Air tanks	544
Water and waste tanks	54
Thermal systems	146
<b>Fixed Life Support Total</b>	<b>888</b>
Consumable air + tanks	591
Consumable water	288
Bulk stowage (NASA spec)	1200
<b>Consumables Total</b>	<b>2079</b>



# Mass Estimates - Summary

Element	Mass (kg)
Structures	3455
Crew Accommodations	537
Fixed Life Support	888
Consumables	2079
<b>Total Mass Estimate</b>	<b>6959</b>

- Dry mass of 4883 kg has 30% margin on 7000 kg limit
- Does not include 861 kg of water for SPE crew shielding
- Considerable mass savings possible by structural optimization (conservative assumptions used throughout)





# Power Estimates - Summary

Element	Power (W)	Duty Cycle	Avg. Power
Air Handling	100	100%	100
2BMS	800	100%	800
TIMES	200	100%	200
Lighting	490	varies	103
Food Preparation	500	5%	25
Thermal	150	100%	150
Avionics	350	60%	210
<b>Peak Power Estimate</b>	<b>2590</b>	<b>Avg. Pwr.</b>	<b>1588</b>
Crew Body Load			400
Solar/Lunar Insolation			4579
<b>Total Thermal Load</b>			<b>6567</b>

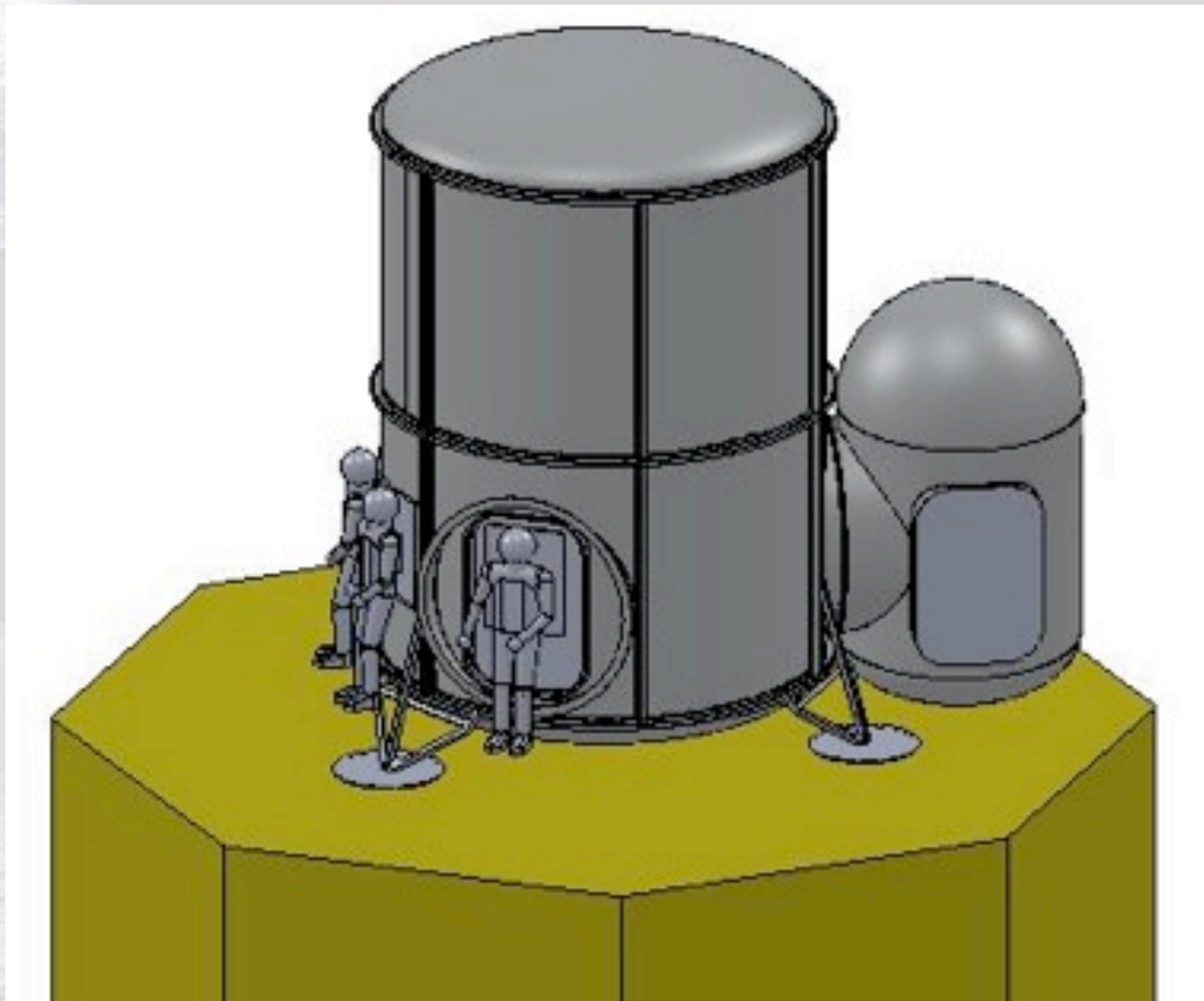


# Stowage Summary

- Cargo Transfer Bag (CTB) direct stowage = 137
  - Lower Deck - 2xCTB cabinets = 48 CTBs
  - Upper Deck - Underberth CTB stowage = 50 CTBs
  - Upper Deck - Galley wall CTB stowage = 15 CTBs
  - Upper Deck - Berth stowage volume = 24 CTBs
- Open stowage volumes (all upper deck)
  - Galley stowage cabinets -  $2 \times 0.36 \text{ m}^3 = 34 \text{ CTB equiv.}$
  - Open berth stowage -  $4 \times 0.24 \text{ m}^3 = 44 \text{ CTB equiv.}$
- Total stowage capacity = 215 CTB equiv. =  $4.6 \text{ m}^3$



# Early Operations on Altair Lander

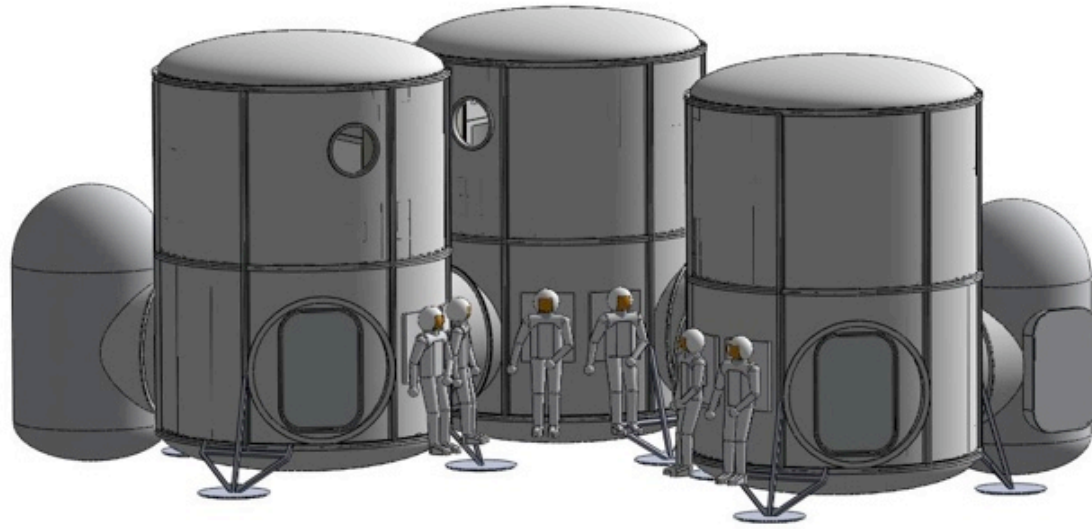
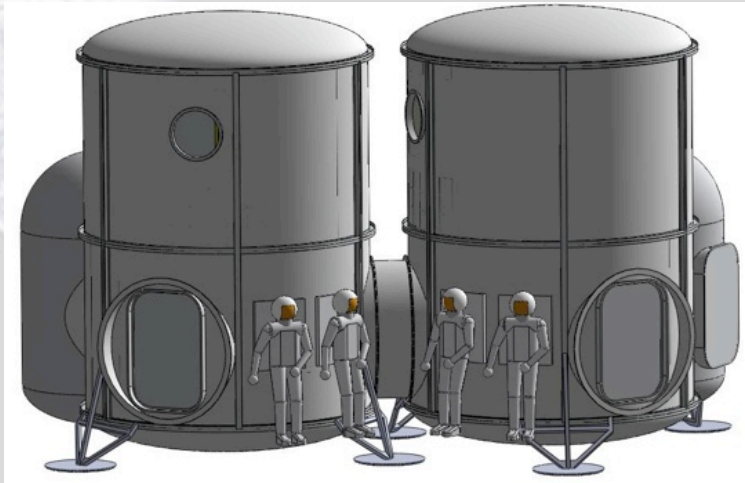


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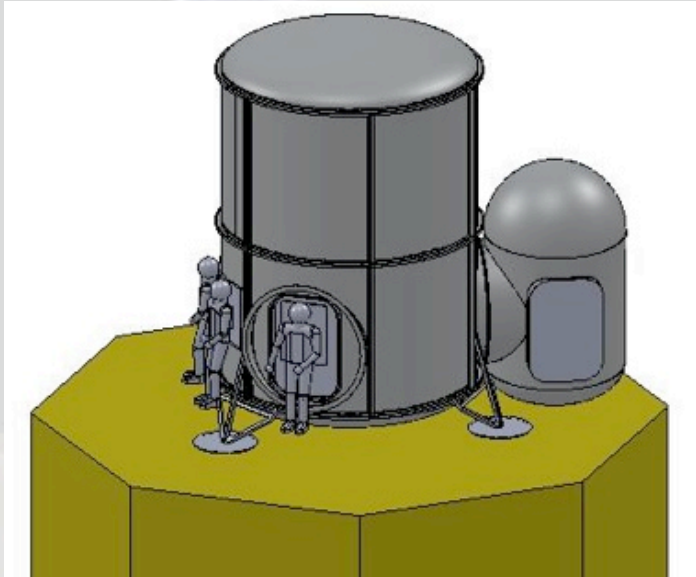
# Growth Options



- Multiple habitats can be docked together to form extended outposts
- ~0.5 m flexible couplers needed between berthing ports
- Smallest closed-loop configuration is six habitats



# Early Operations on Altair Lander



- With addition of power generating/storage capability, this class of habitats could be used for stand-alone missions of up to two months anywhere on the moon
- Cargo lander payload would accommodate habitat, PSU, and rover



# Accomplishments

- Performed fundamental research to frame architecture questions and provide design database
- Investigated personnel priorities based on analogue experiences
- Developed four preliminary habitat designs
- Developed and performed preliminary testing of full-scale two-level habitat
- Performed detailed design of minimal functionality habitat, with extensions to indefinite durations





# Potential Follow-ons

- Much interesting research remaining to be done
  - Increase fidelity in full-scale mockup
  - Quantitative evaluation of efficacy of VR habitability assessments
  - Demonstration of “wireless” command/control/data network
  - Continue habitat design in greater depth
  - Integrate full-scale habitat mockup into field trials
  - Study interactions with rovers, surface robotics
  - Extend AHP/QFD survey to flight crew and mission ops
- We appreciate the opportunity to be involved with Constellation and hope to be able to continue...

